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(54) **WIRELESS IC DEVICE**

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See application file for complete search history.

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(57) **ABSTRACT**

A wireless IC device includes a dielectric body, a metal pattern that is provided on a surface of the dielectric body and that defines a radiator, and a wireless IC element coupled to feeding portions of the metal pattern. A plurality of slits are provided on at least one surface of the dielectric body so as to provide flexibility for the dielectric body.

16 Claims, 18 Drawing Sheets

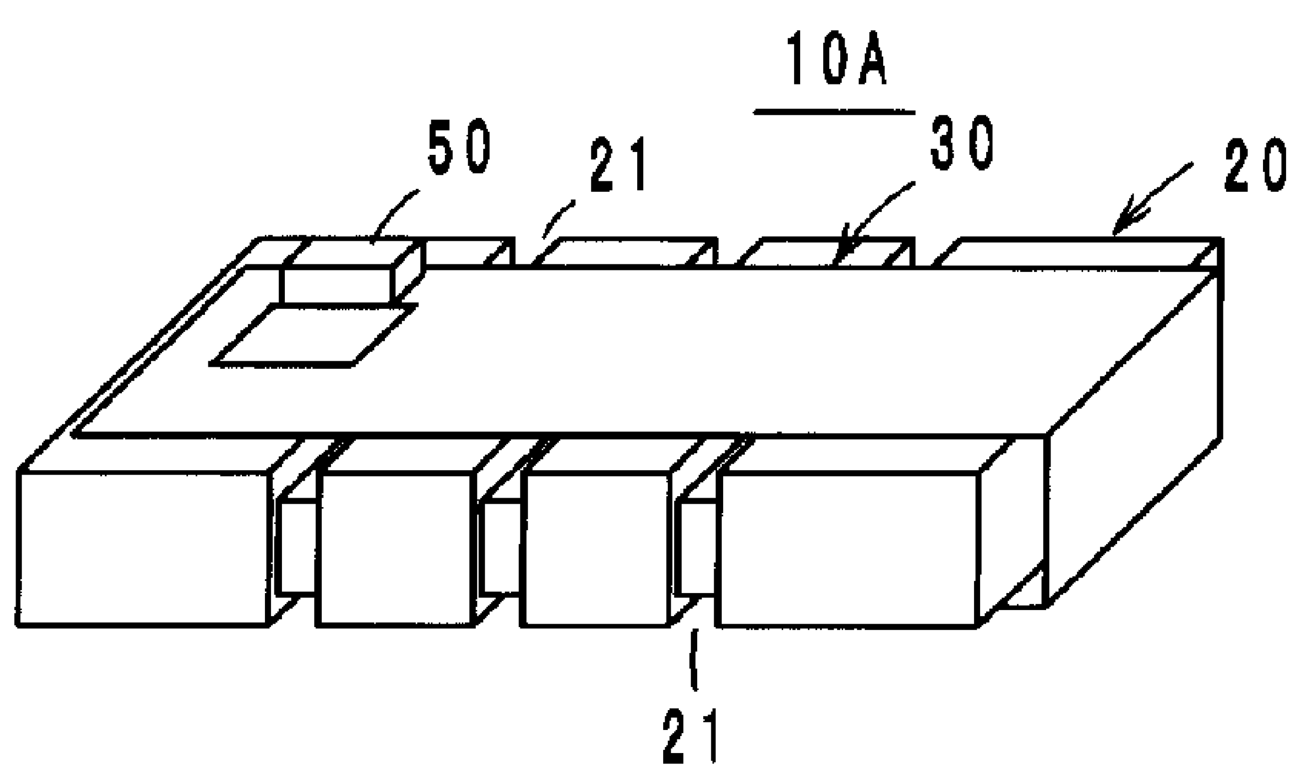

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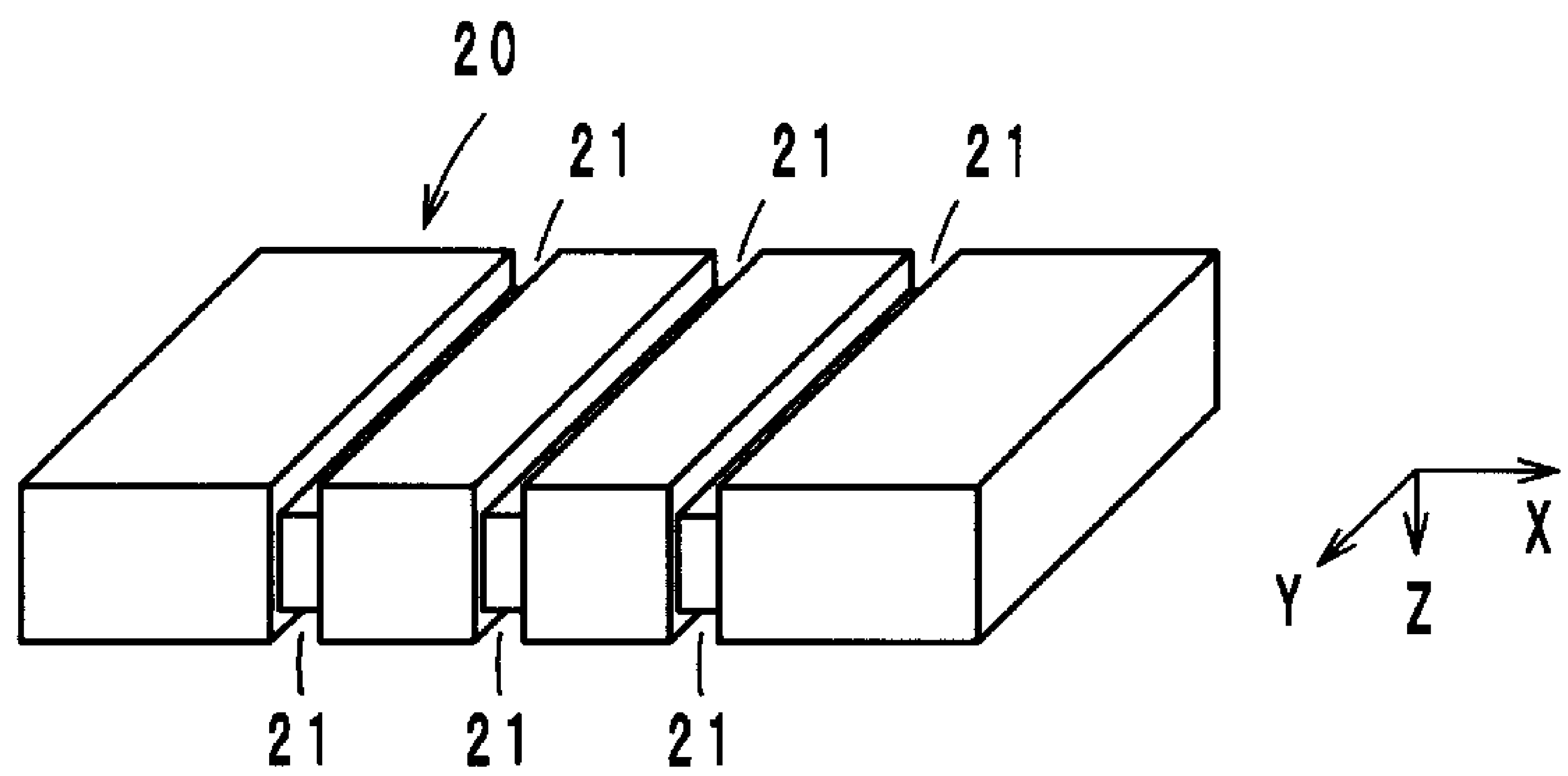
FIG. 1A



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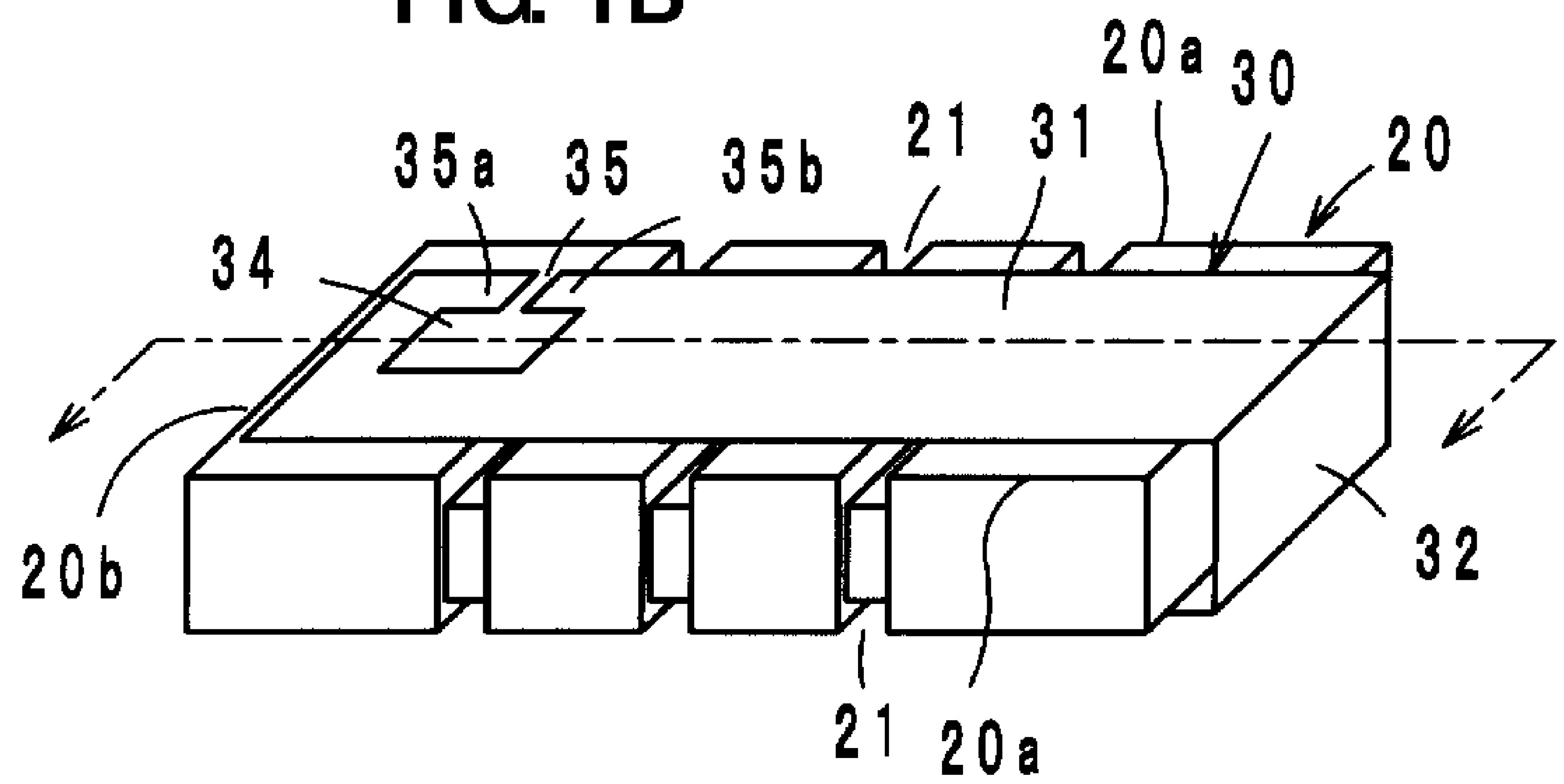


FIG. 1C

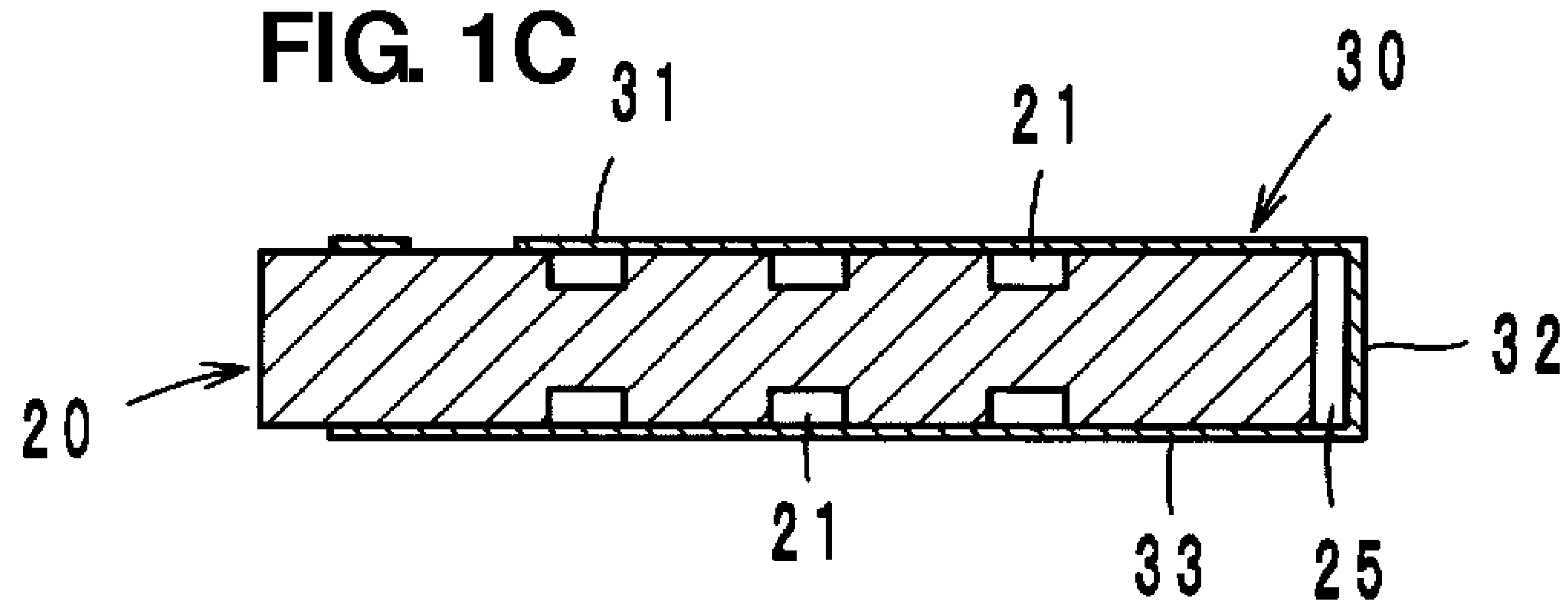


FIG. 1D

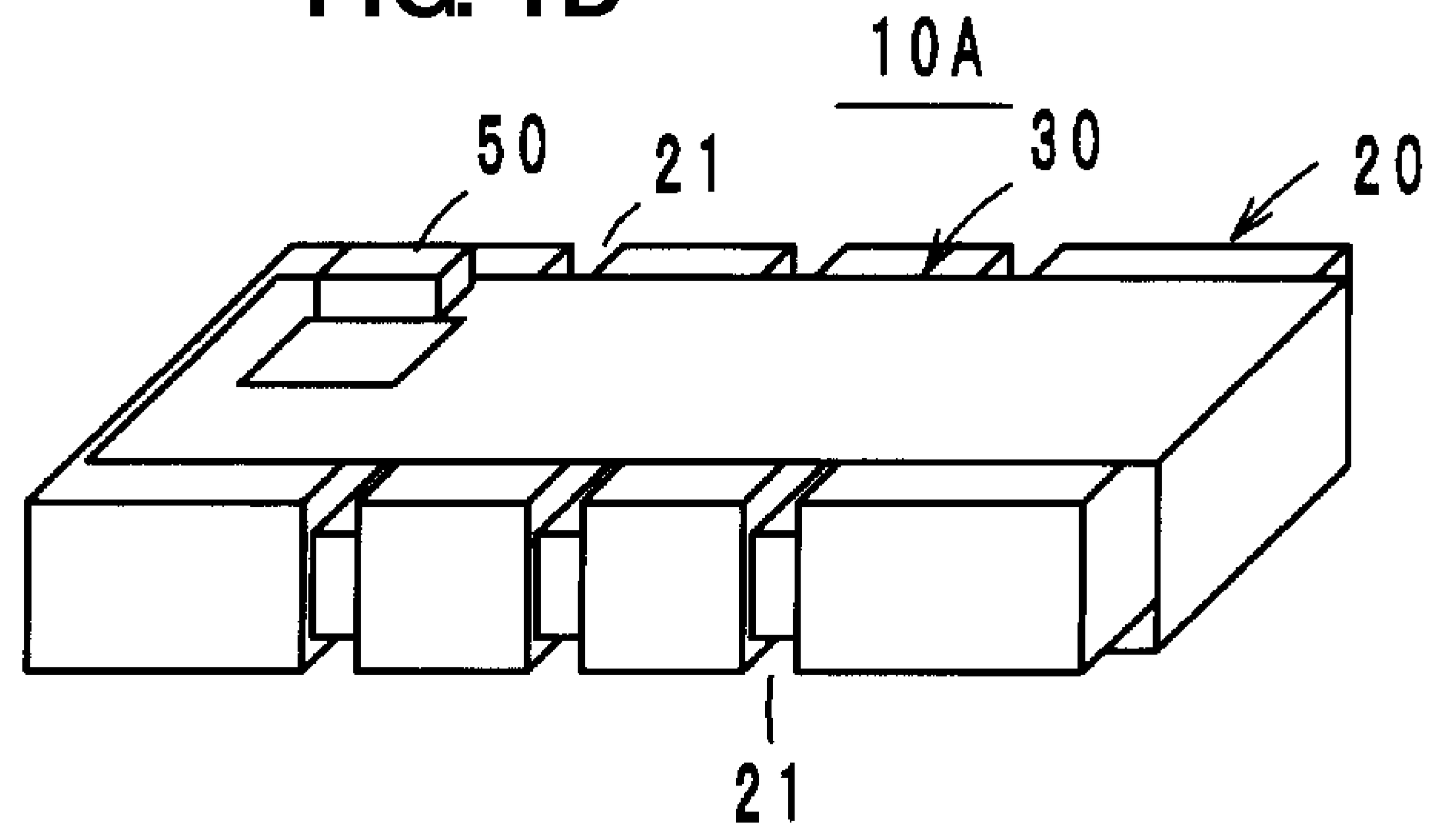


FIG. 2A

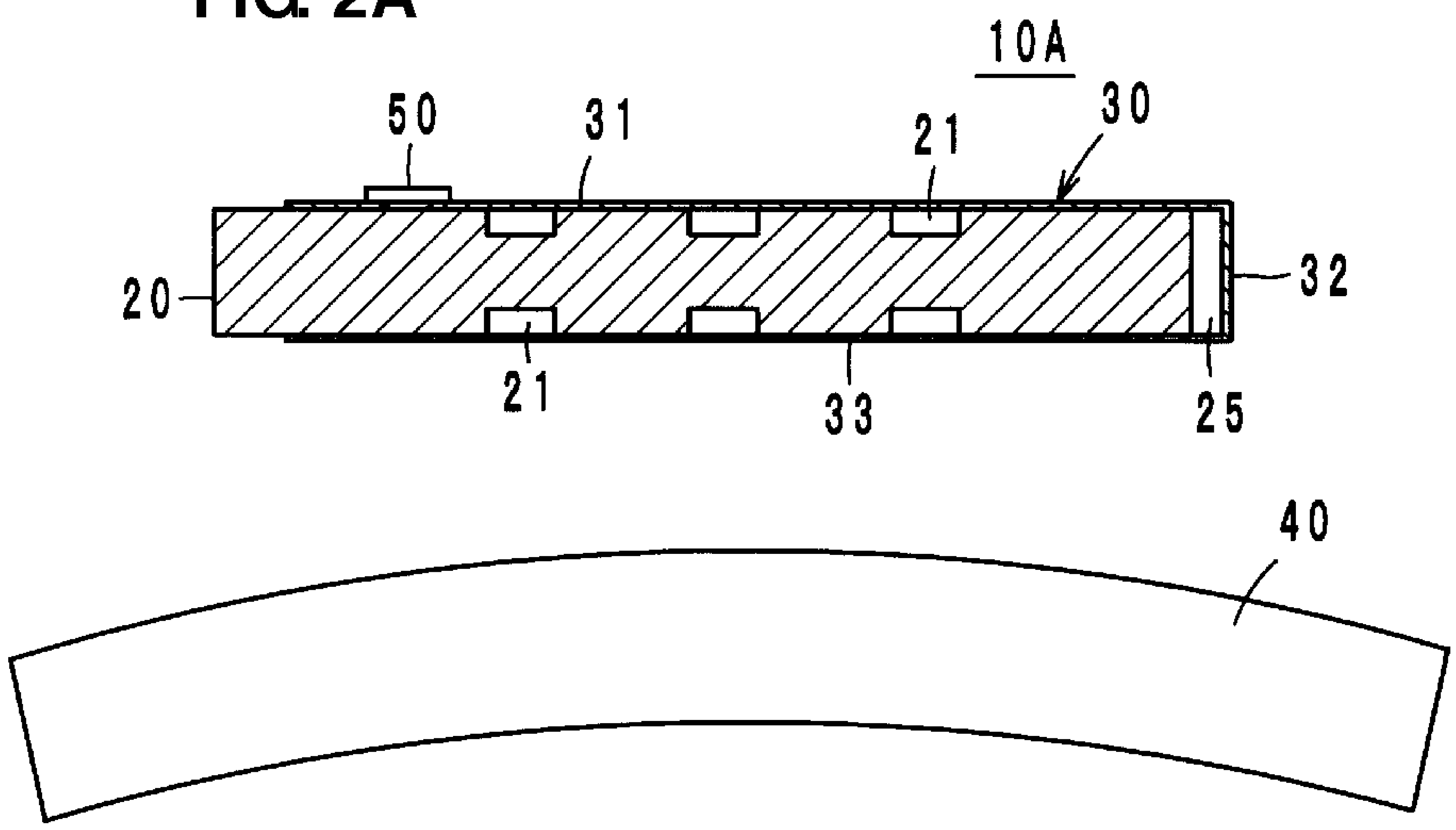


FIG. 2B

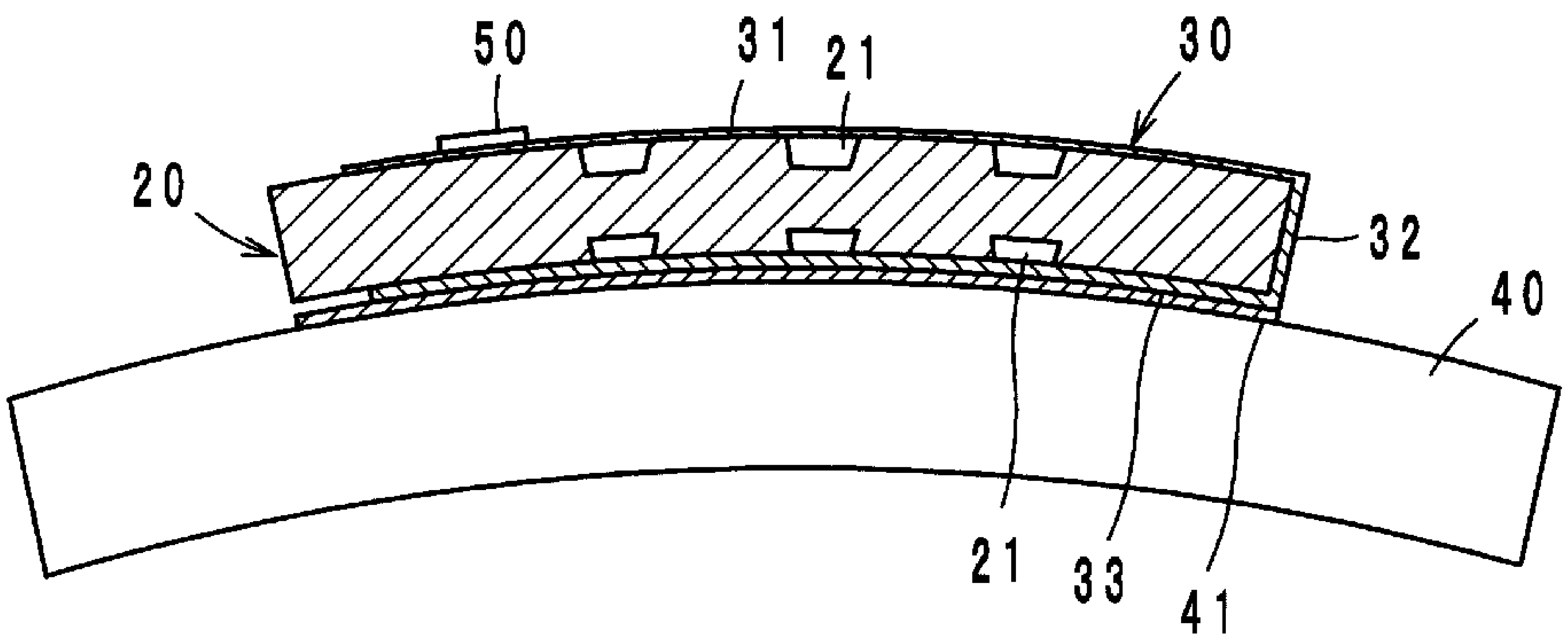
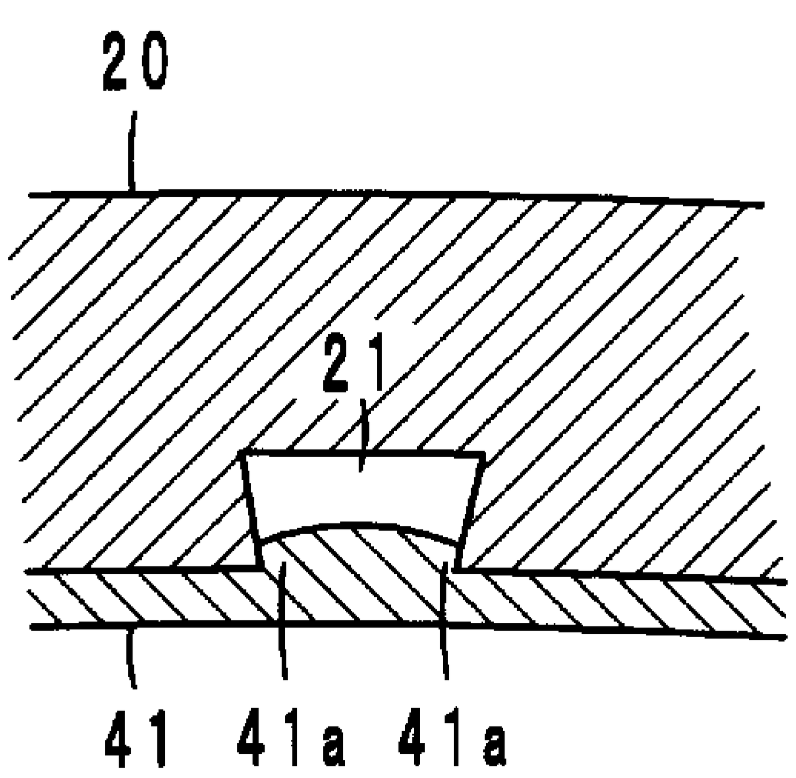


FIG. 3A



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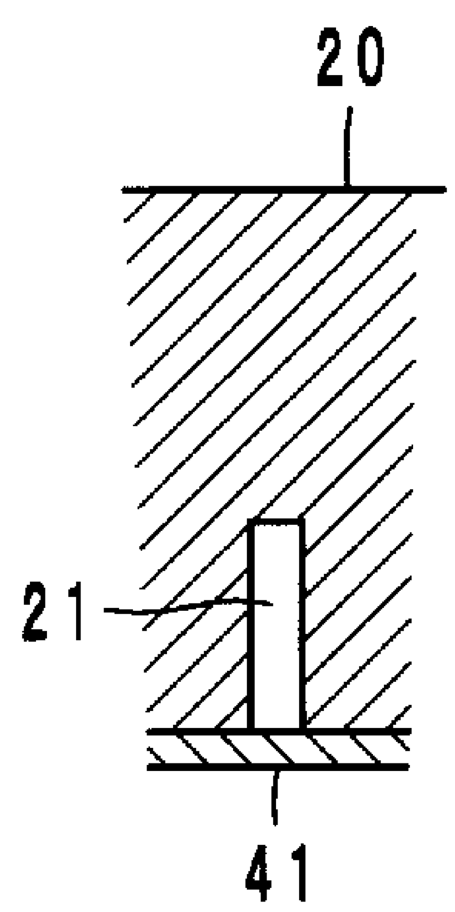


FIG. 3C

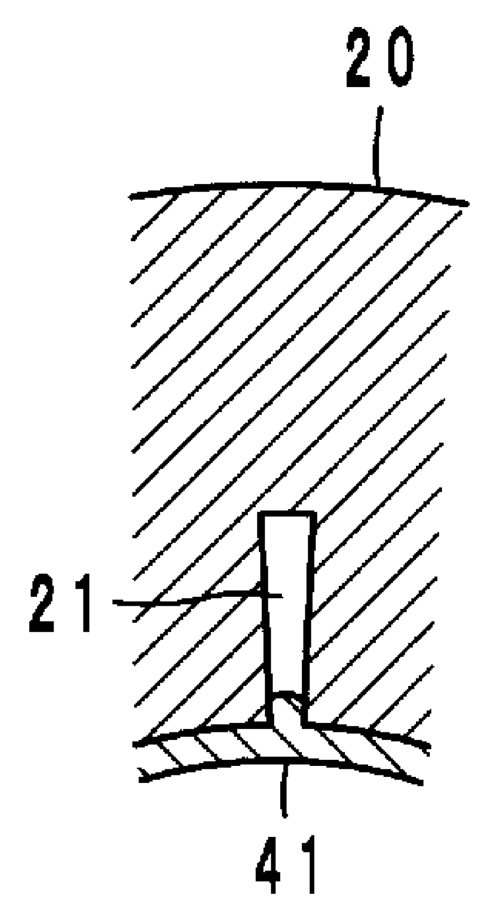
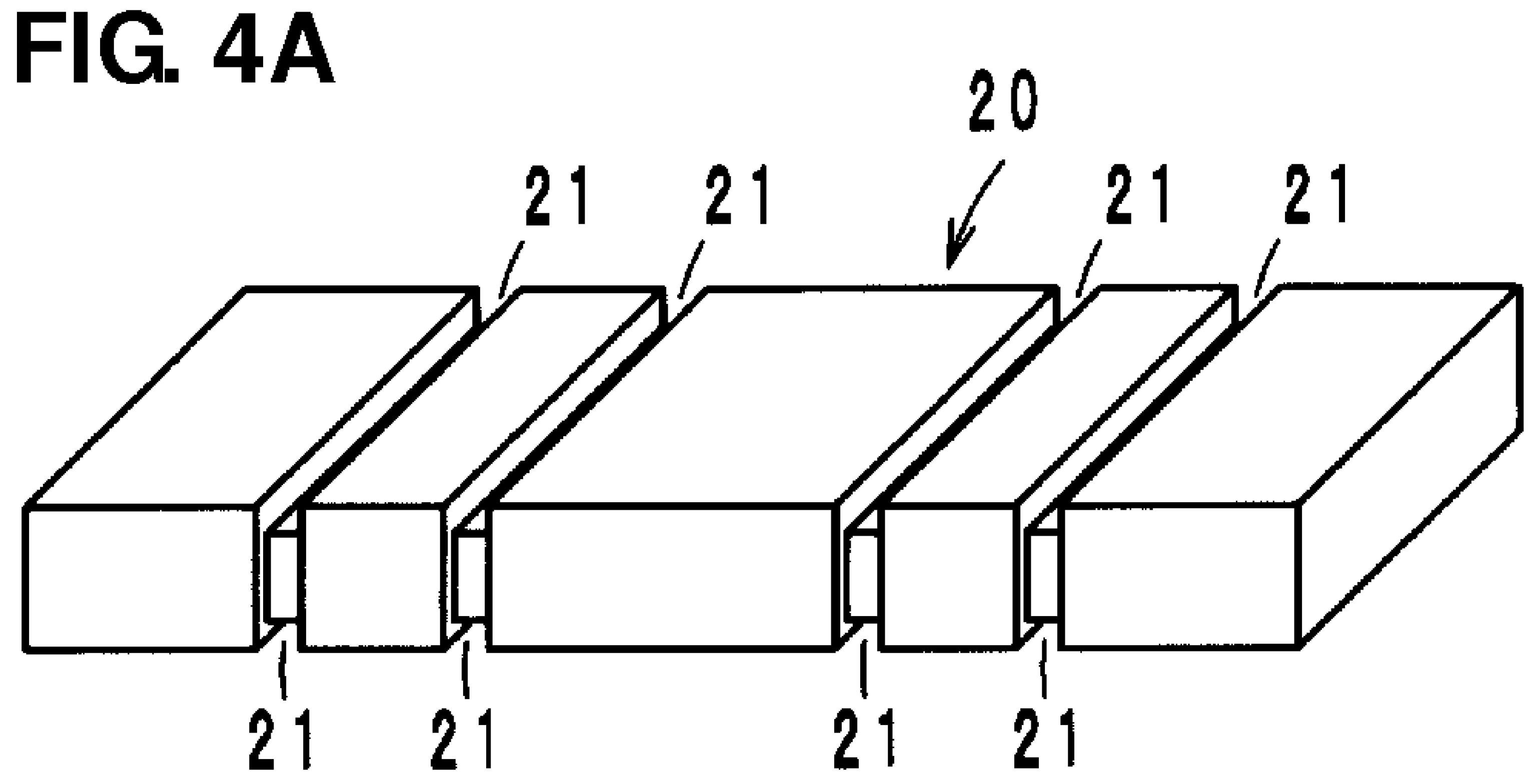


FIG. 4A



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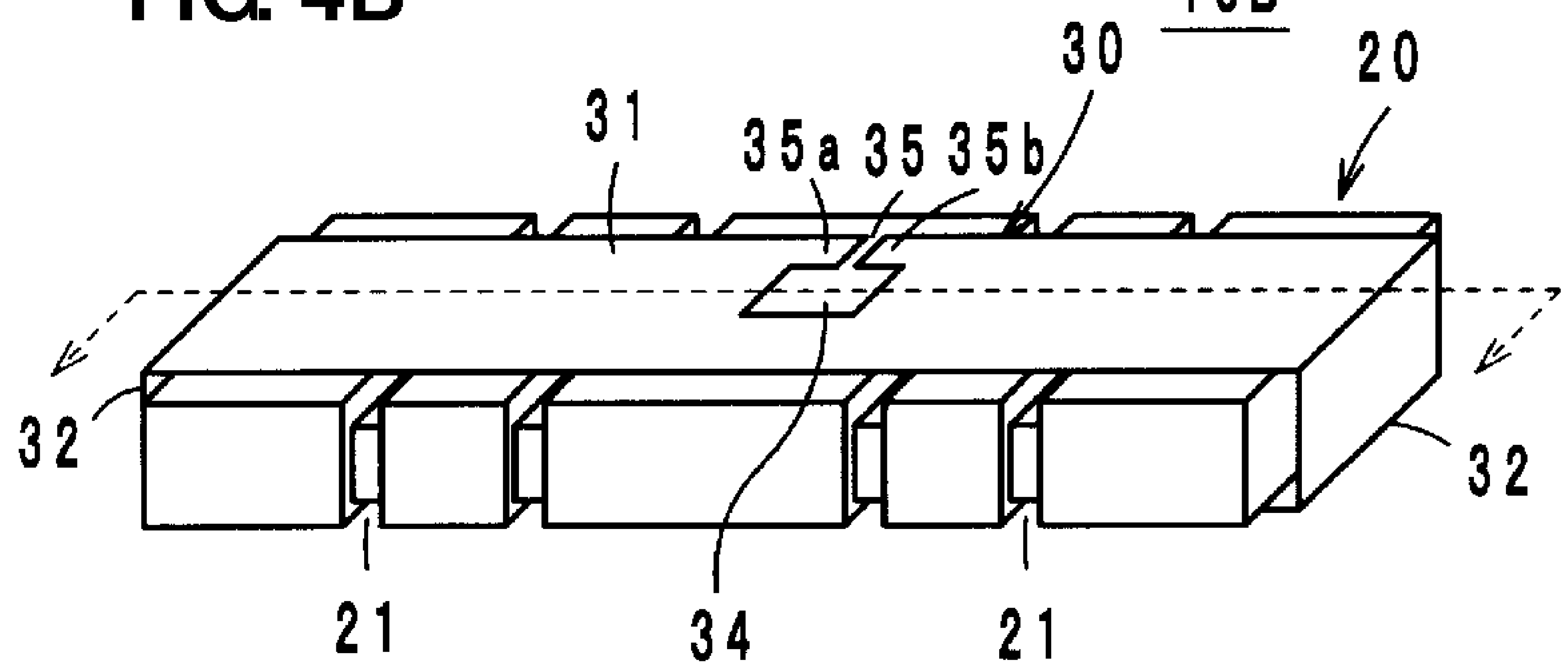

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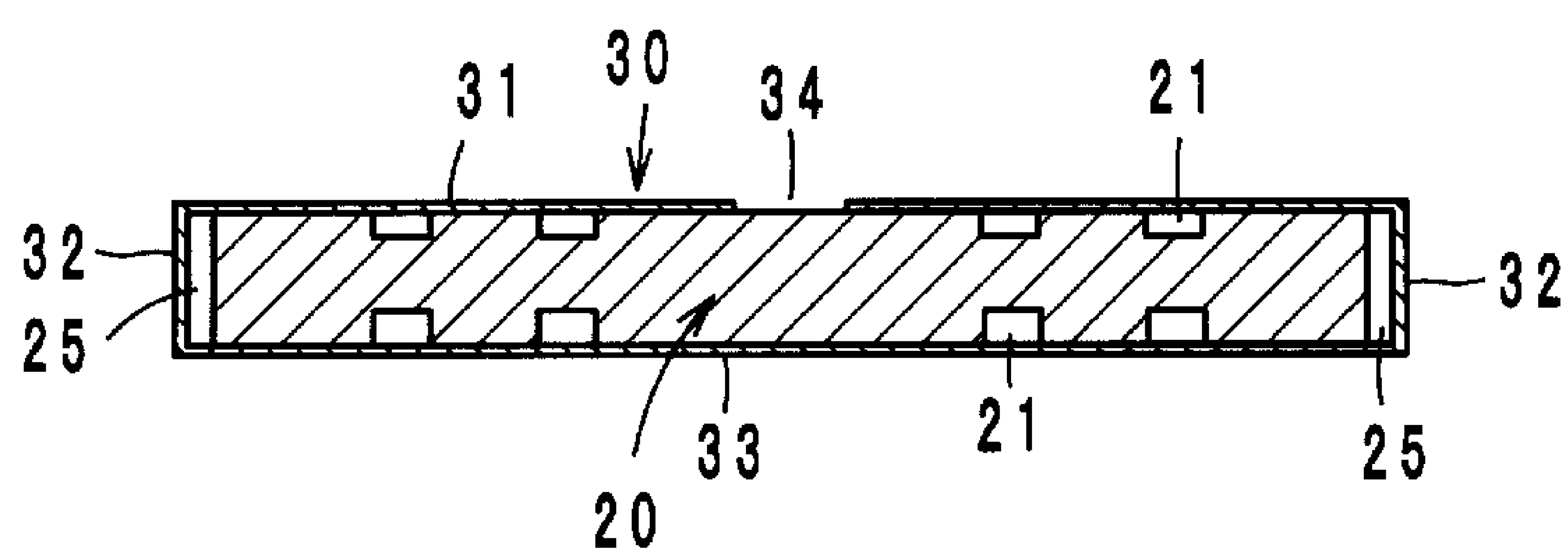
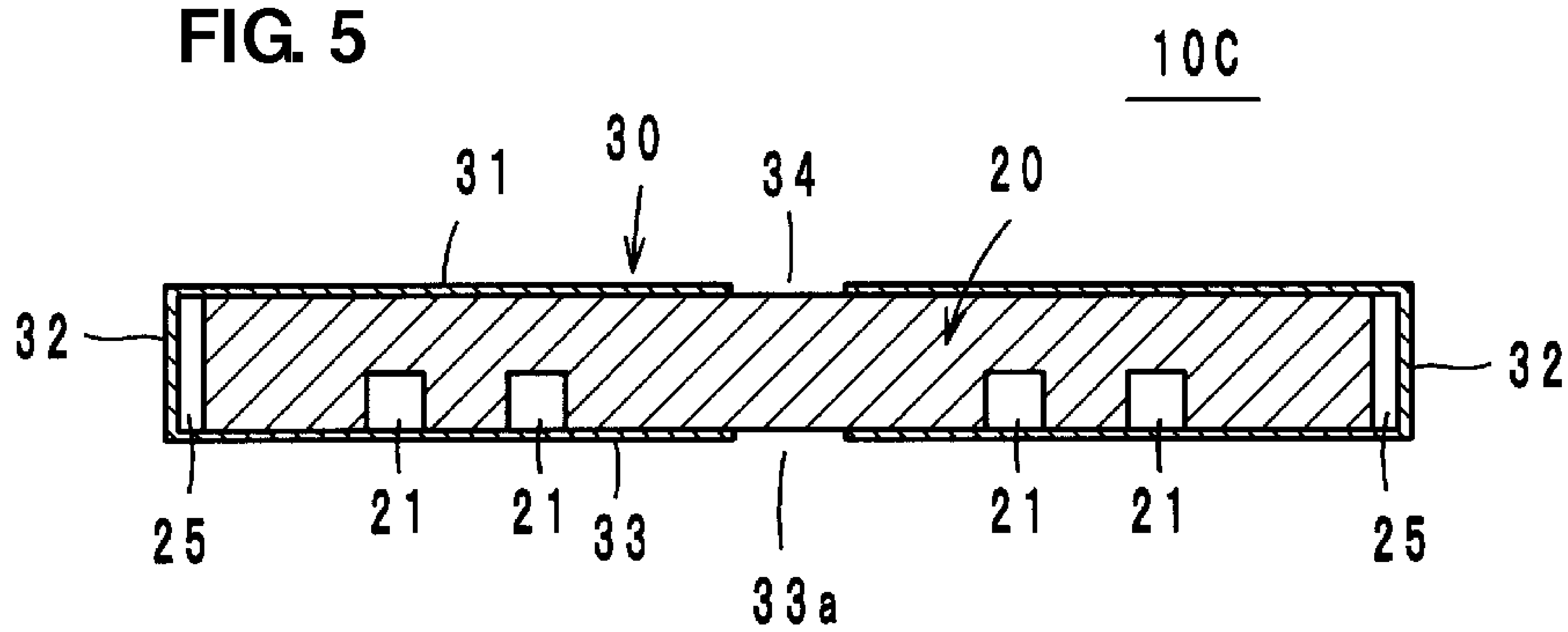


FIG. 5



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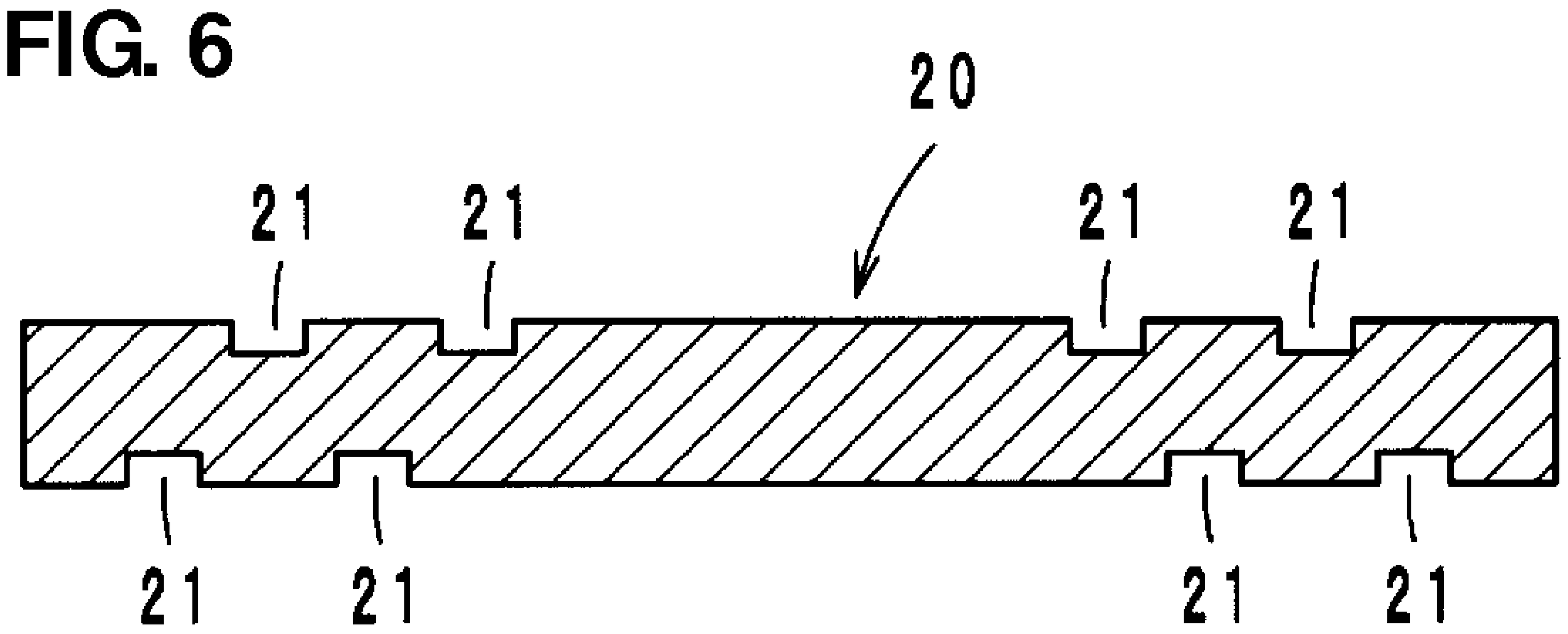

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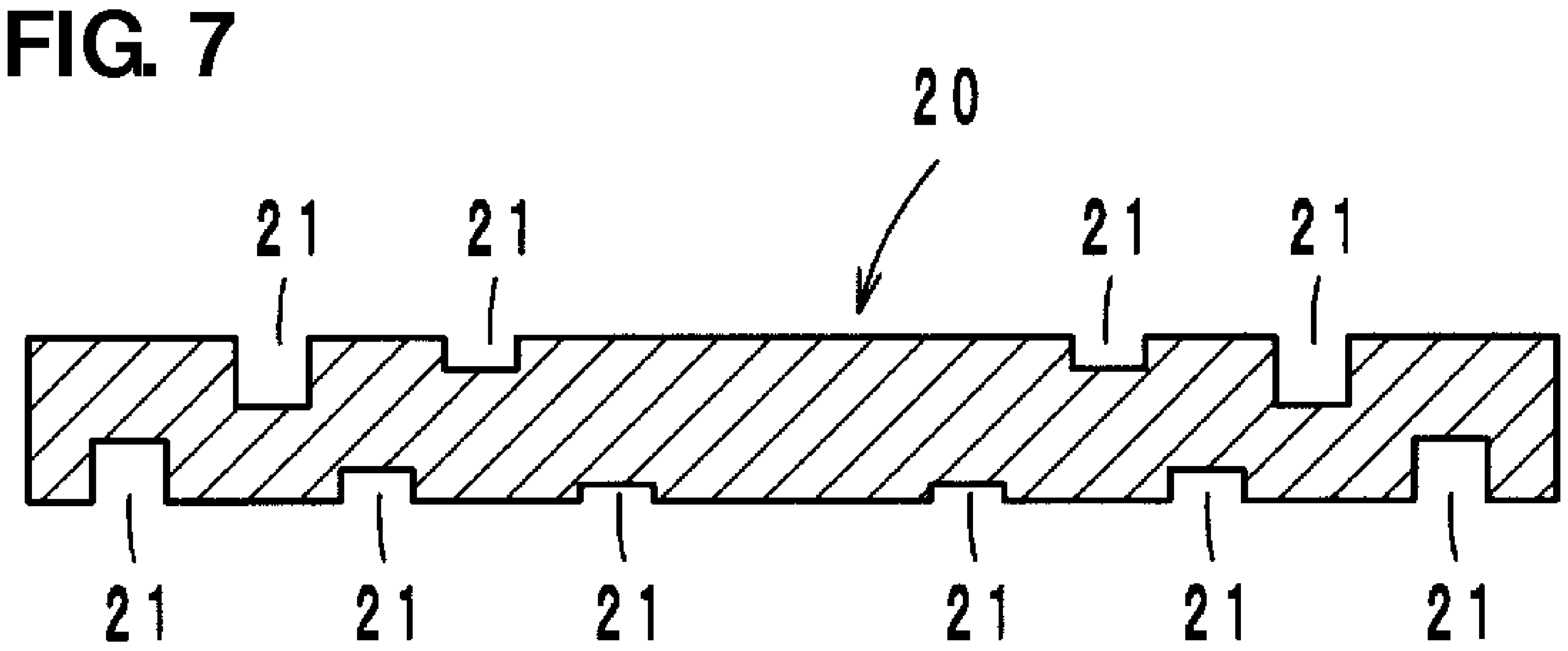

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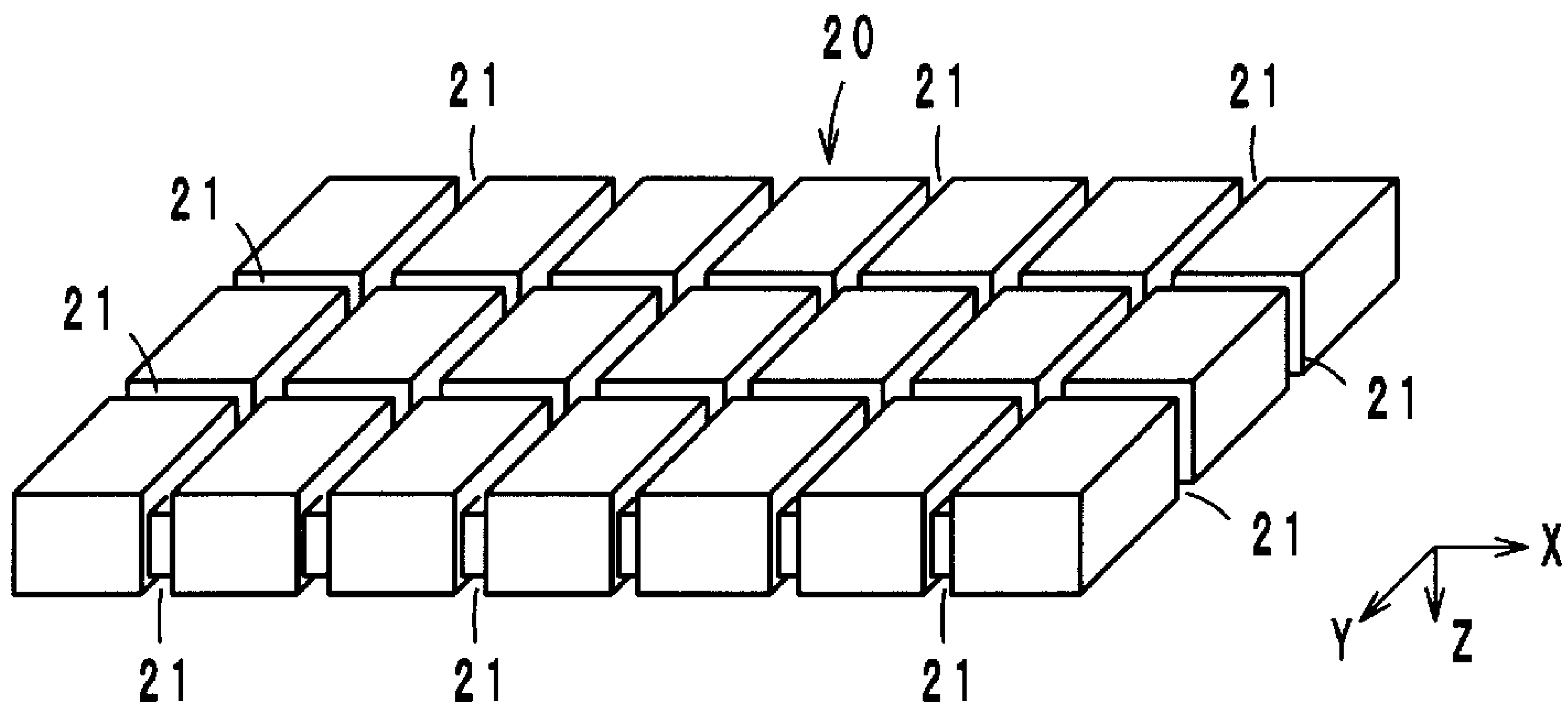

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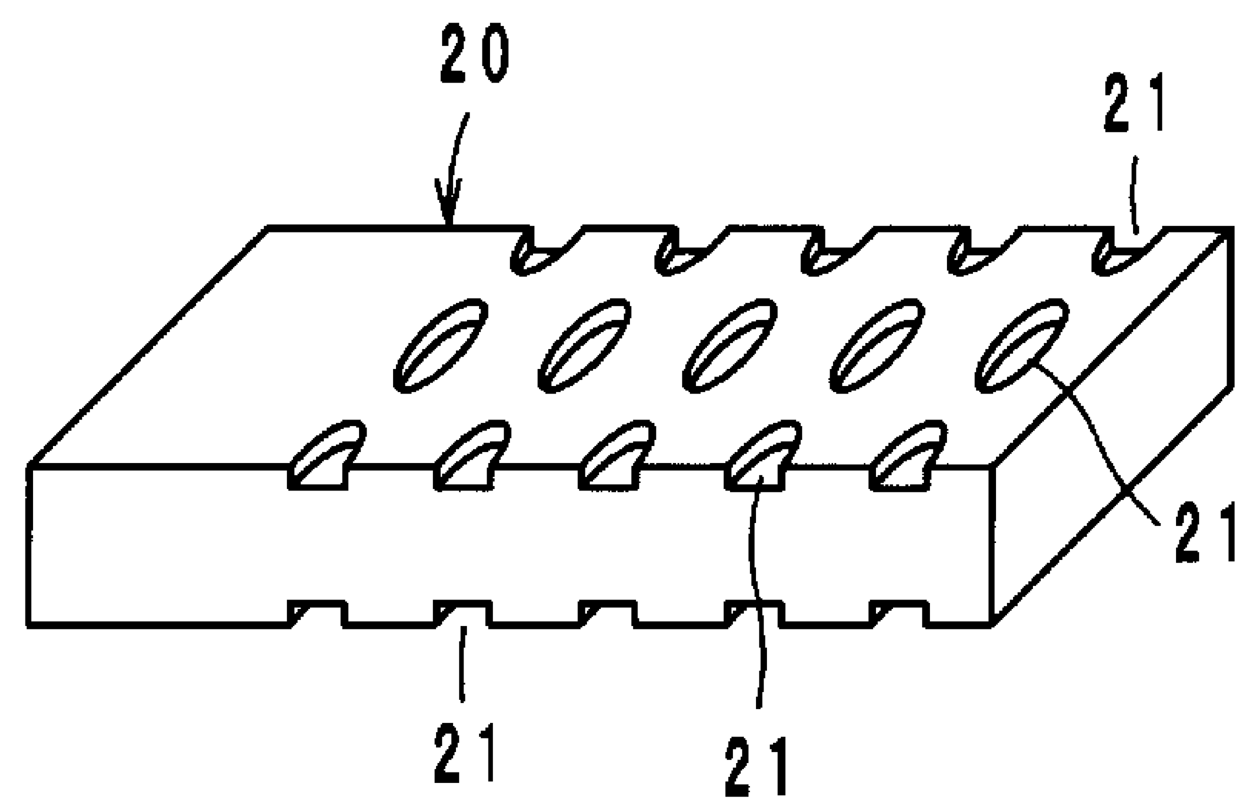


FIG. 10A

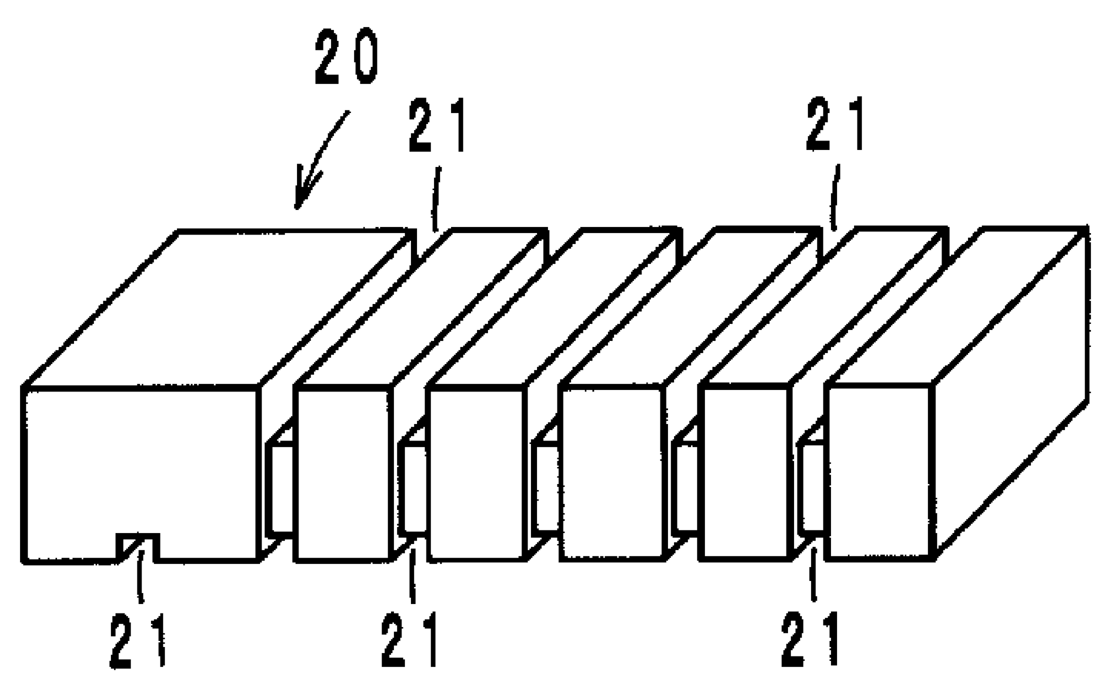


FIG. 10B

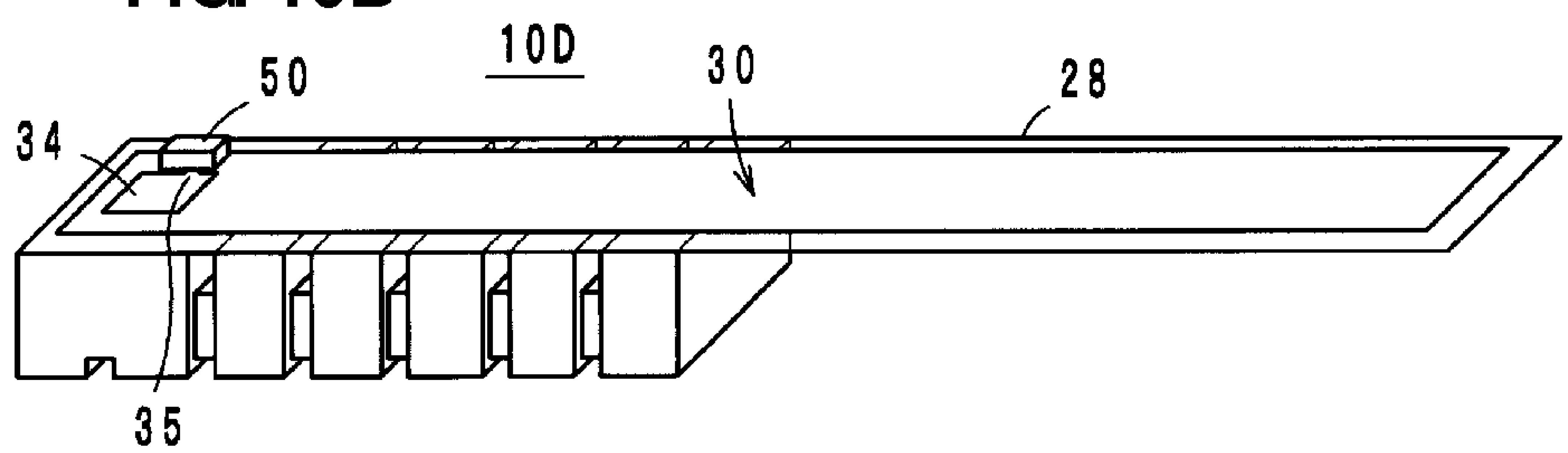


FIG. 10C

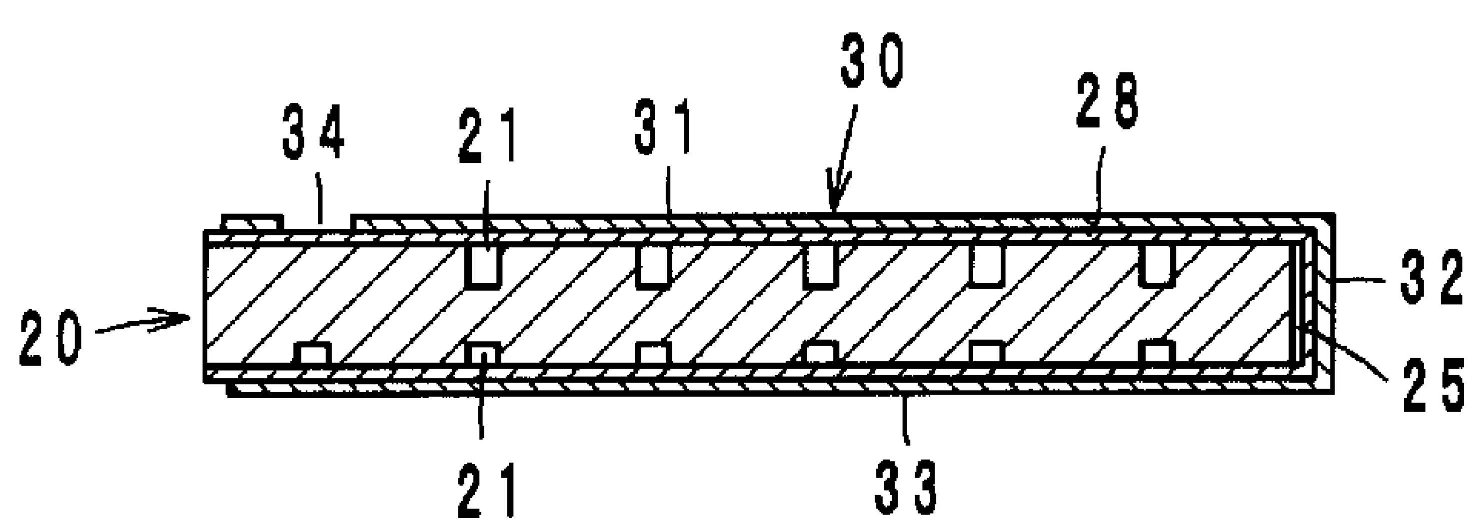


FIG. 11

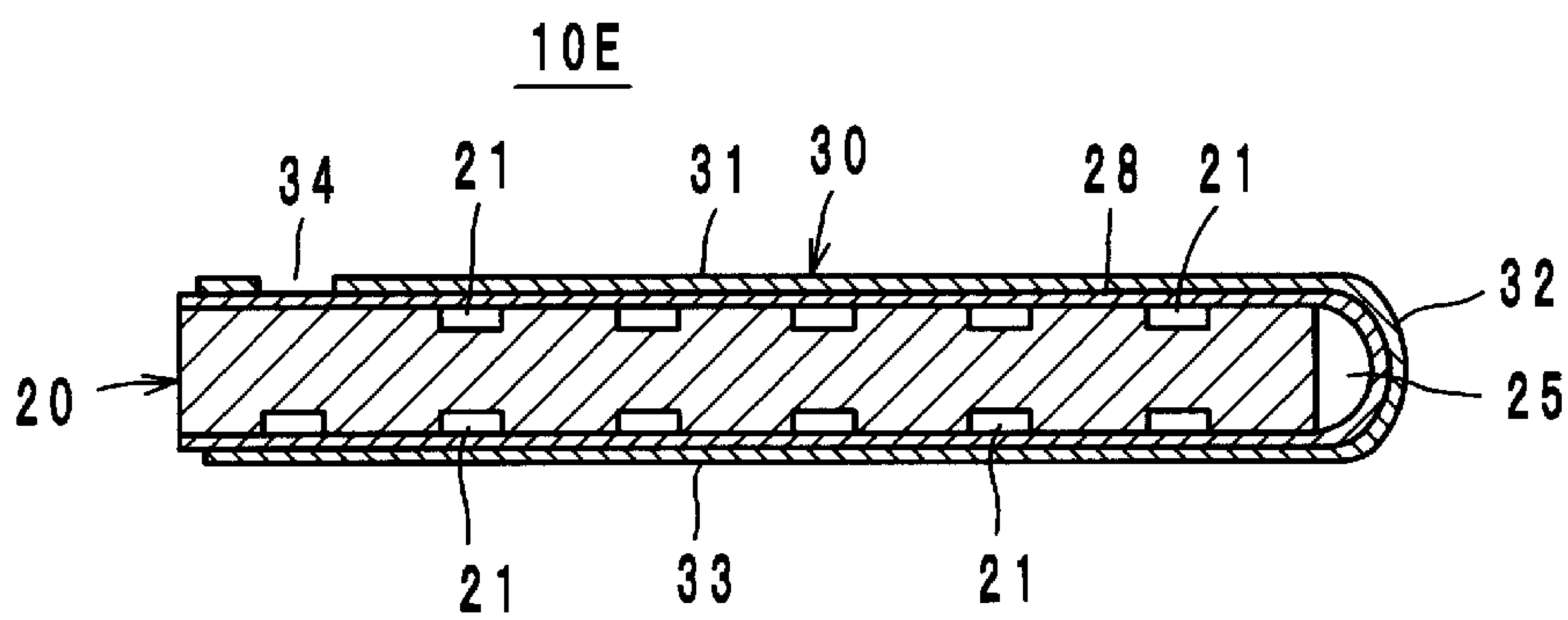


FIG. 12

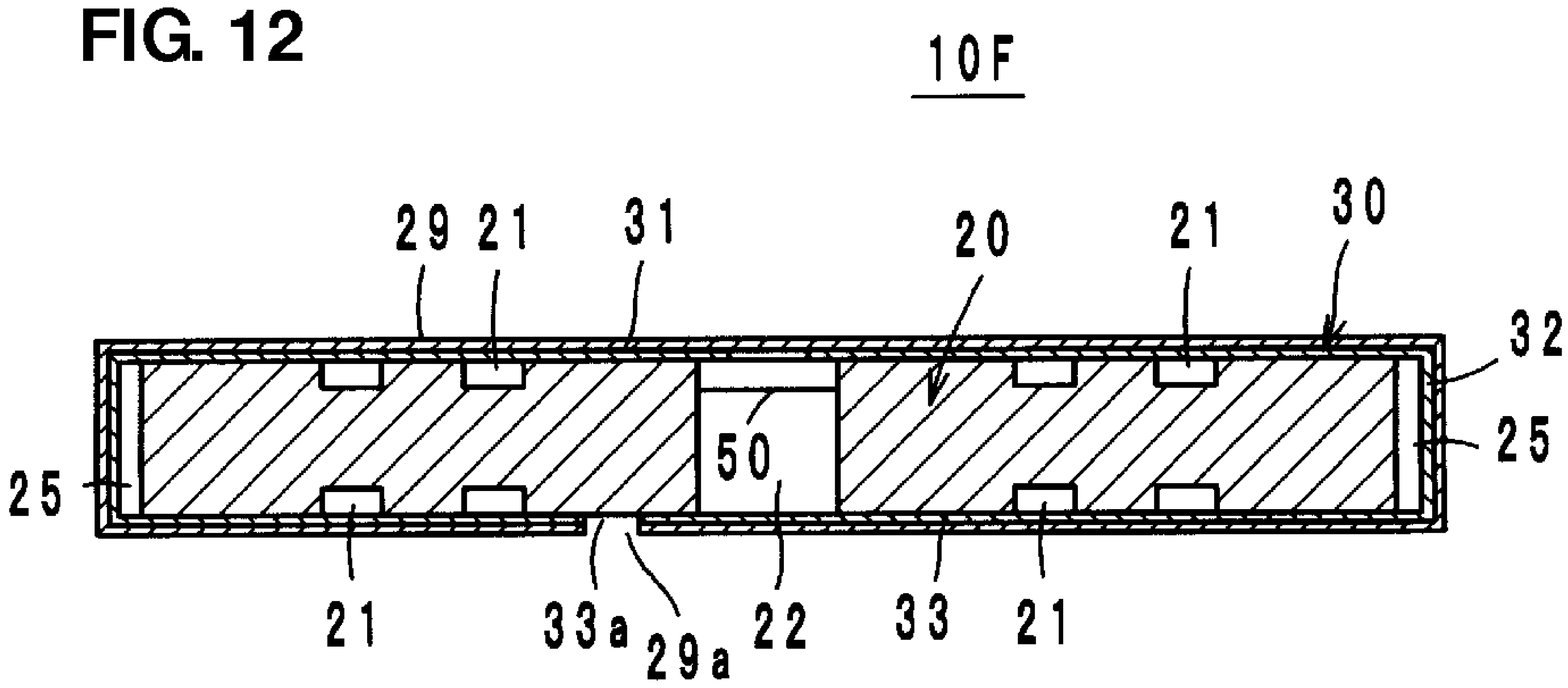


FIG. 13

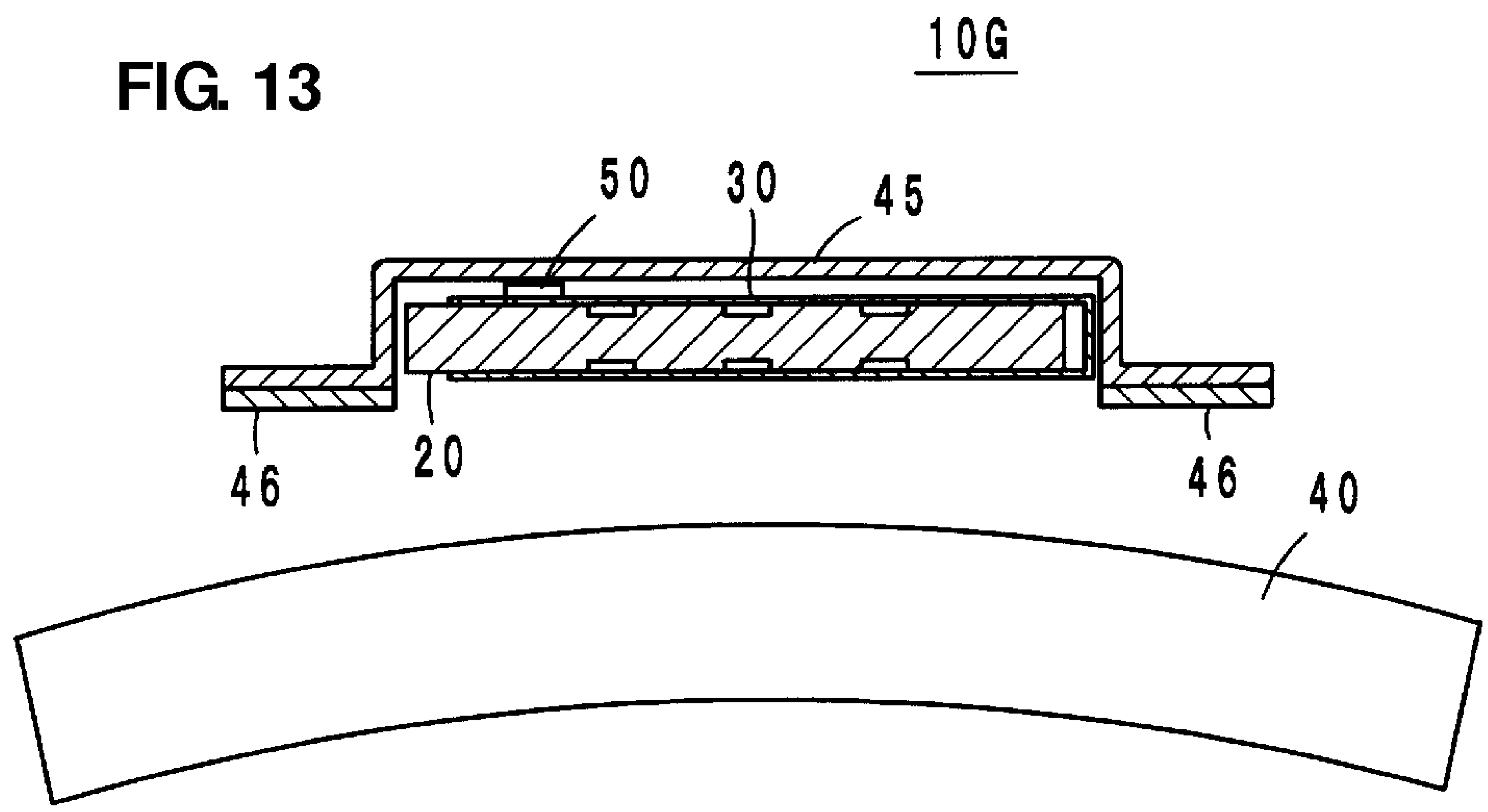


FIG. 14

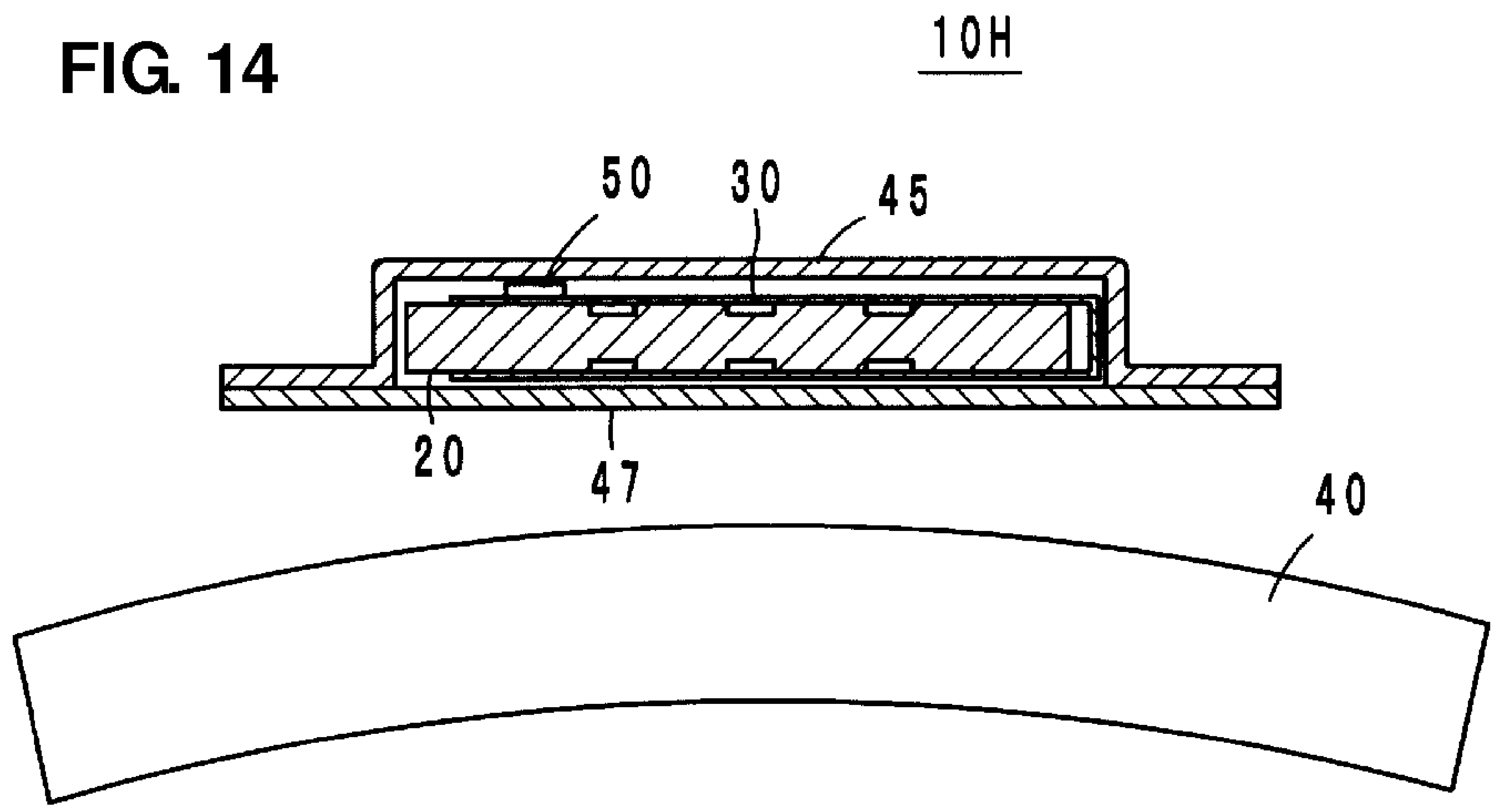


FIG. 15

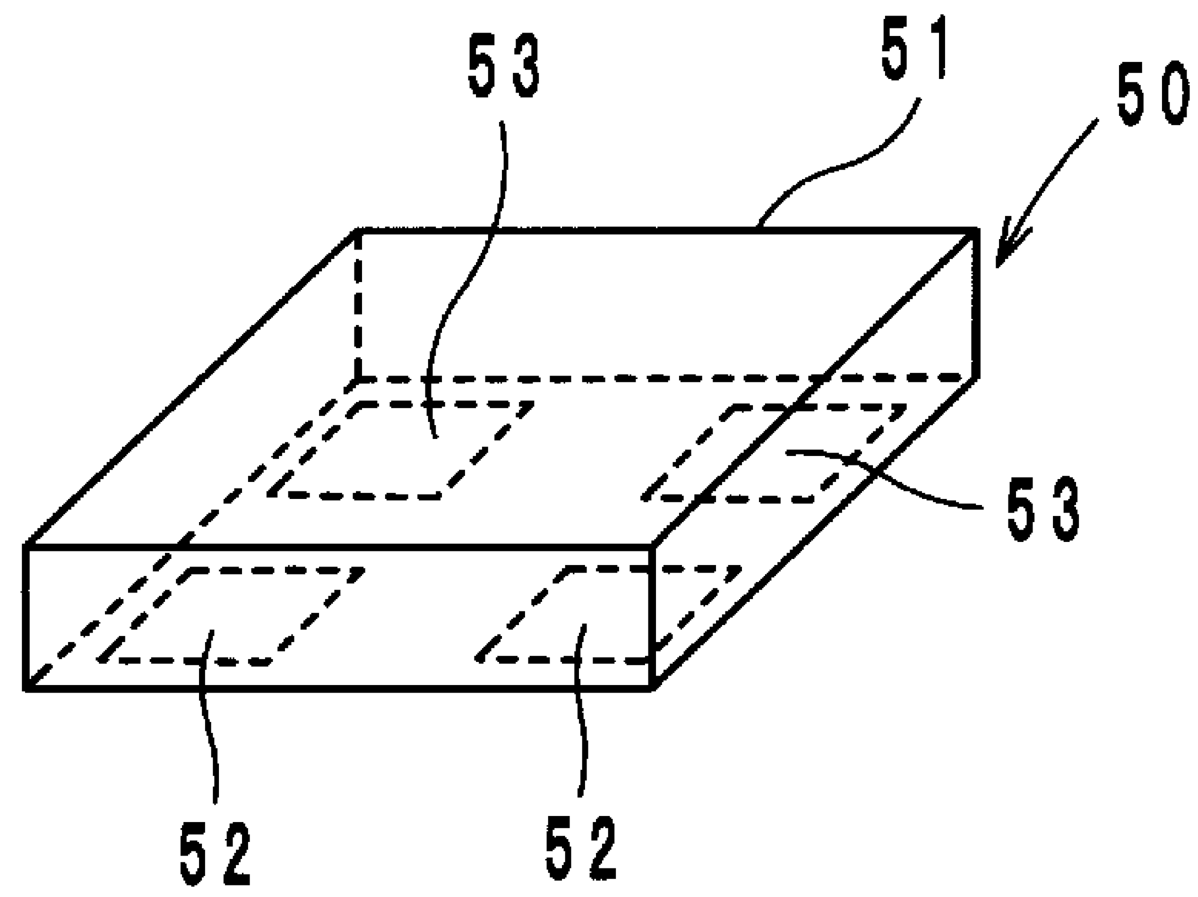


FIG. 16

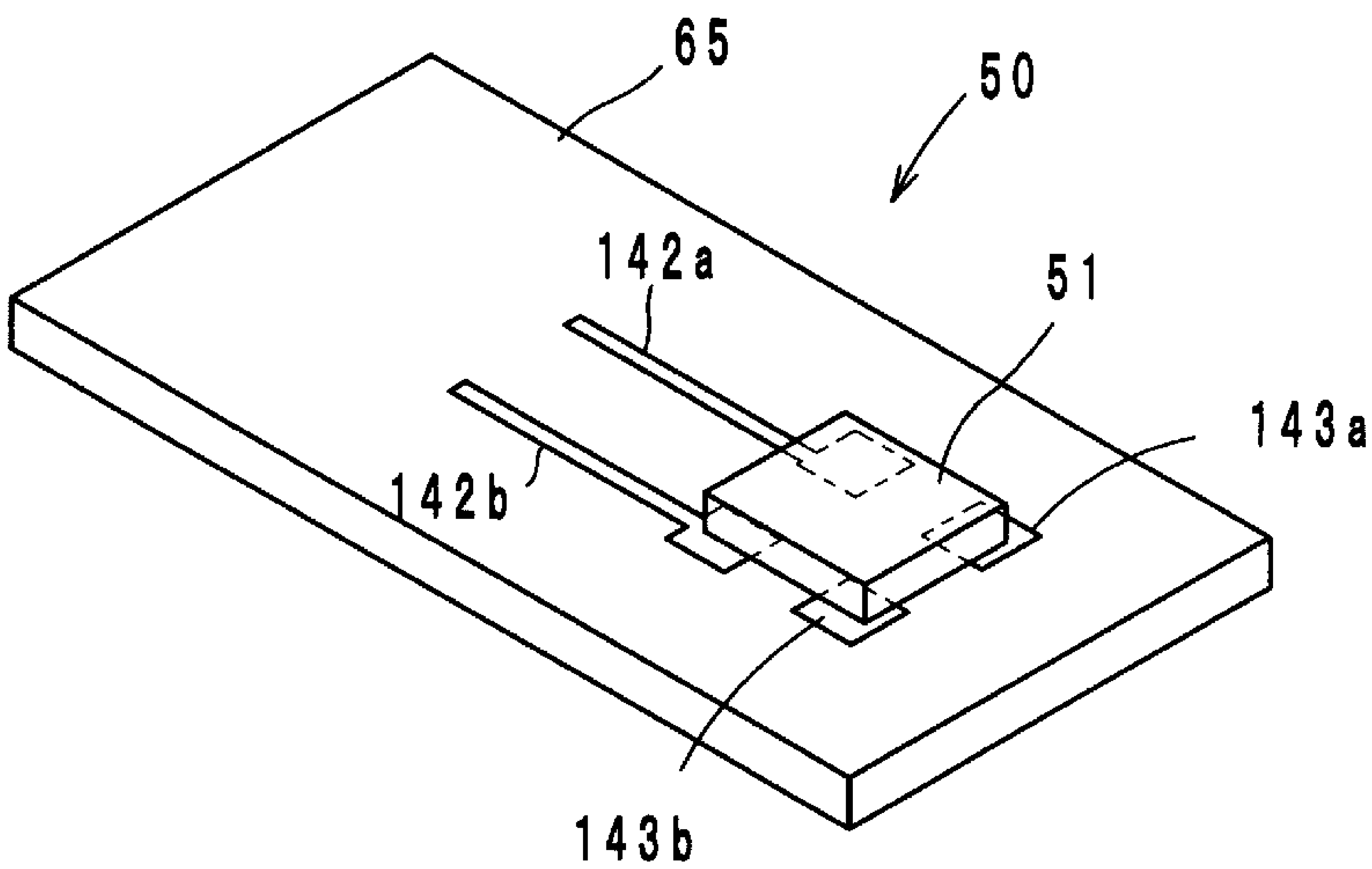


FIG. 17

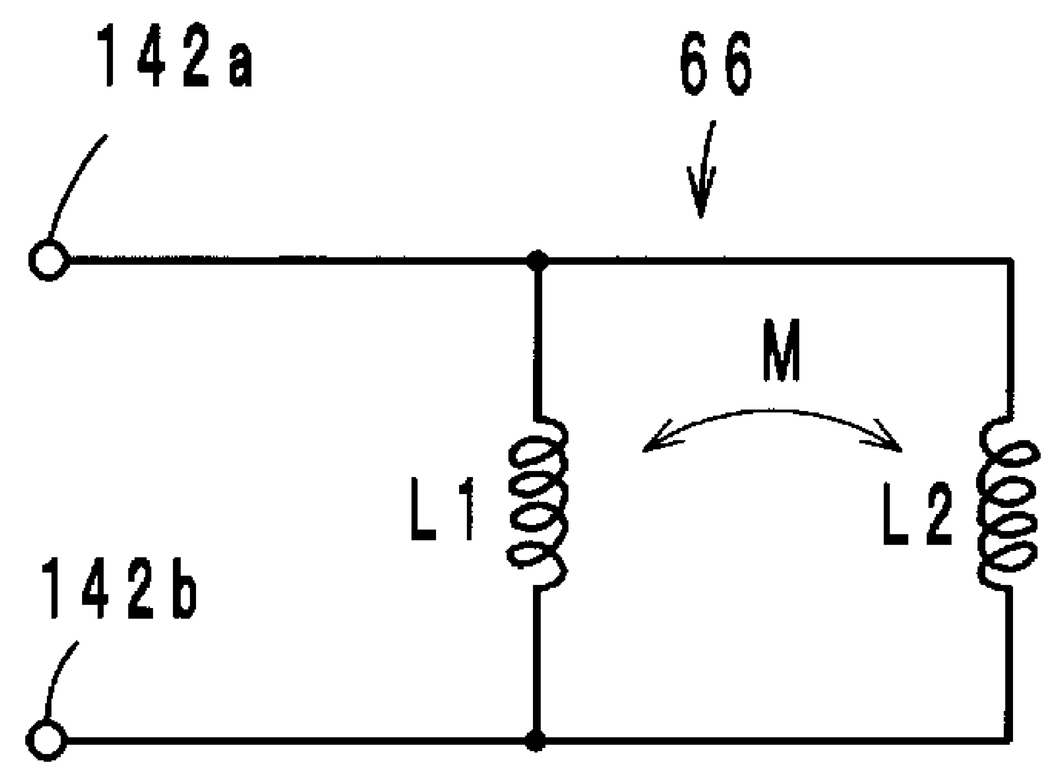
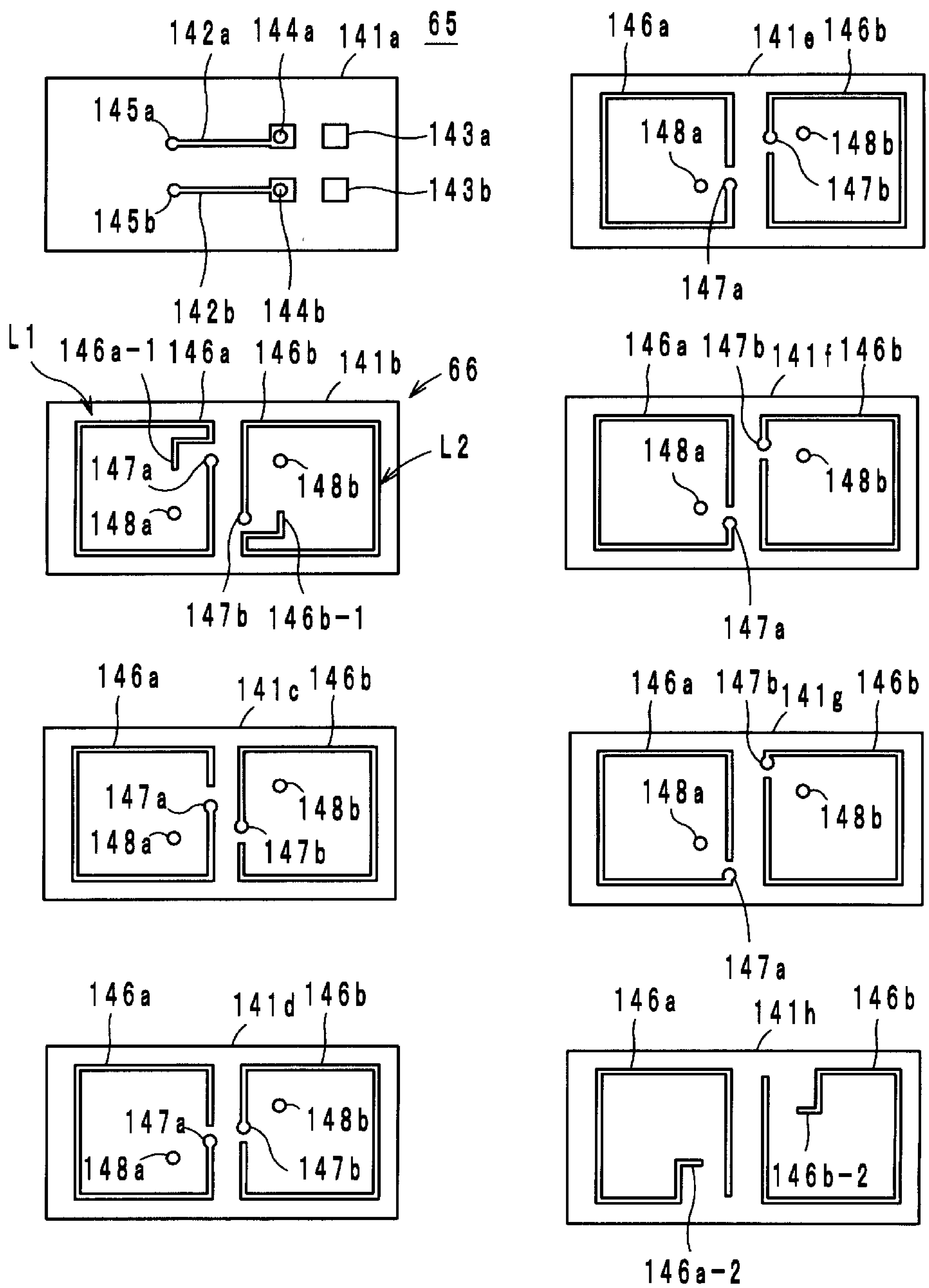


FIG. 18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WIRELESS IC DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to wireless IC devices, and, more particularly, to a wireless IC device preferably for use in a Radio Frequency Identification (RFID) system.

2. Description of the Related Art

In recent years, as information management systems for products, RFID systems have been used in which transmission of predetermined information is performed in a non-contact manner between a reader/writer for generating an induction field and an RFID tag (hereinafter also referred to as a wireless IC device) attached to a product. The RFID tag includes a wireless IC chip for storing predetermined information and processing a predetermined radio signal and an antenna (radiator) for transmitting/receiving a high-frequency signal, and is attached to various management target products (or packages of these products).

Japanese Unexamined Patent Application Publication No. 2007-272264 discloses this type of RFID tag obtained by providing a loop antenna on an insulating film, disposing a wireless IC chip at the loop antenna, and wrapping the insulating film around a dielectric member.

Products to which such RFID tags are attached have various shapes. For example, a gas cylinder has a curved surface, and it is required that an RFID tag can be attached to the curved surface. When the RFID tag disclosed in Japanese Unexamined Patent Application Publication No. 2007-272264 includes a dielectric member made of a material such as silicon, the RFID tag can be attached to a curved surface. However, if an RFID tag is attached to a curved surface using only the flexibility of a material, stress concentration may occur between a dielectric member and a loop antenna when the dielectric member is bent. As a result, the loop antenna may be detached from the dielectric member, or a crack may be produced at the dielectric member. Alternatively, the loop antenna may be distorted, a communication characteristic may be changed, and communication reliability may be reduced.

SUMMARY OF THE INVENTION

To overcome the problems described above, preferred embodiments of the present invention provide a wireless IC device in which detachment of a radiator from a body and changes in a communication characteristic are prevented even if the wireless IC device is attached to a curved surface.

A wireless IC device according to a preferred embodiment of the present invention preferably includes a dielectric body including an upper surface and a lower surface, a radiator provided on a surface of the dielectric body, and a wireless IC element coupled to a feeding portion of the radiator. The radiator is preferably a flexible metal pattern. A plurality of concave portions are preferably provided on at least one of the surfaces of the dielectric body to provide flexibility for the dielectric body.

A wireless IC device according to another preferred embodiment of the present invention preferably includes a dielectric body including an upper surface and a lower surface, a radiator provided on a surface of the dielectric body, and a wireless IC element coupled to a feeding portion of the radiator. The radiator is a metal pattern having flexibility. A plurality of concave portions are preferably provided on at least the surface of the dielectric body to provide flexibility

for the dielectric body. The dielectric body is preferably attached to a surface of a metal body, for example.

In the wireless IC device, the radiator is preferably a flexible metal pattern, and the dielectric body has flexibility due to a plurality of concave portions provided on at least the surface thereof. Accordingly, even if the wireless IC device is attached to the curved surface of a product (metal body), the dielectric body and the radiator follow the curved surface and stress concentration between the dielectric body and the radiator does not occur. As a result, changes in a communication characteristic caused by the detachment of the radiator from the dielectric body and the distortion of the radiator are prevented, and communication reliability is not reduced. By attaching the wireless IC device to the metal body, the metal body functions as a radiating element and a communication distance is increased.

According to various preferred embodiments of the present invention, detachment of a radiator from a body and changes in a communication characteristic are prevented even if a wireless IC device is attached to a curved surface.

The above and other elements, features, steps, characteristics and advantages of the present invention will become more apparent from the following detailed description of the preferred embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a perspective view of a dielectric body in a wireless IC device according to a first preferred embodiment of the present invention.

FIG. **1**B is a perspective view of the dielectric body on which a radiator is provided.

FIG. **1**C is a cross-sectional view of the dielectric body on which the radiator is provided.

FIG. **1**D is a perspective view of the wireless IC device according to the first preferred embodiment of the present invention in which a wireless IC element is disposed at the radiator on the dielectric body.

FIG. **2**A is a cross-sectional view illustrating a wireless IC device according to the first preferred embodiment of the present invention and a product to which the wireless IC device is to be attached.

FIG. **2**B is a cross-sectional view of the wireless IC device according to the first preferred embodiment of the present invention attached to the product.

FIGS. **3**A, **3**B, and **3**C are diagrams describing operations of slits provided in a dielectric body.

FIG. **4**A is a perspective view of a dielectric body in a wireless IC device according to a second preferred embodiment of the present invention.

FIG. **4**B is a perspective view of the dielectric body on which a radiator is provided.

FIG. **4**C is a cross-sectional view of the dielectric body on which the radiator is provided.

FIG. **5** is a cross-sectional view of a wireless IC device according to a third preferred embodiment of the present invention.

FIG. **6** is a cross-sectional view of a first modification of the dielectric body according to a preferred embodiment of the present invention.

FIG. **7** is a cross-sectional view of a second modification of the dielectric body according to a preferred embodiment of the present invention.

FIG. **8** is a perspective view of a third modification of the dielectric body according to a preferred embodiment of the present invention.

FIG. **9** is a perspective view of a fourth modification of the dielectric body according to a preferred embodiment of the present invention.

FIG. **10**A is a perspective view of a dielectric body in a wireless IC device according to a fourth preferred embodiment of the present invention.

FIG. **10**B is a perspective view of the dielectric body on which a radiator is provided.

FIG. **10**C is a cross-sectional view of the dielectric body on which the radiator is provided.

FIG. **11** is a cross-sectional view of a wireless IC device according to a fifth preferred embodiment of the present invention.

FIG. **12** is a cross-sectional view of a wireless IC device according to a sixth preferred embodiment of the present invention.

FIG. **13** is a cross-sectional view of a wireless IC device according to a seventh preferred embodiment of the present invention.

FIG. **14** is a cross-sectional view of a wireless IC device according to an eighth preferred embodiment of the present invention.

FIG. **15** is a perspective view of a wireless IC chip that is a wireless IC element.

FIG. **16** is a perspective view of a feeding circuit board including the wireless IC chip, which is a wireless IC element, thereon.

FIG. **17** is an equivalent circuit diagram illustrating an example of a feeding circuit.

FIG. **18** is a plan view illustrating a laminated structure of the feeding circuit board.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A wireless IC device according to preferred embodiments of the present invention will be described below with reference to the accompanying drawings. In the drawings, the same reference numerals are used to represent the same component or the same element so as to avoid repeated explanation.

First Preferred Embodiment

A wireless IC device **10**A according to the first preferred embodiment of the present invention is preferably used for communication in a UHF band, and preferably includes a substantially rectangular parallelepiped dielectric body **20**, a metal pattern **30** defining a radiator, and a wireless IC element **50** as illustrated in FIGS. **1**A to **1**D.

The dielectric body **20** is preferably made of a dielectric, such as a fluorocarbon resin or a urethane resin, for example, and may also be an insulating magnetic substance. A plurality of slits **21** are preferably provided on the upper surface, lower surface, and side surfaces (on the front and back sides in FIG. **1**A) of the dielectric body **20**. The dielectric body **20** is preferably made of a flexible material, and the flexibility in the thickness direction (Z direction) is increased with the slits **21** extending in a widthwise direction (Y direction) on the surfaces.

The metal pattern **30** is preferably made of a flexible conductive material, such as a copper foil or an aluminum foil, for example. The metal pattern **30** extends from the upper surface to the lower surface through a side surface (on the right side in FIG. **1**A) of the dielectric body **20**, and includes an upper electrode **31**, a side electrode **32**, and a lower electrode **33**. The upper electrode **31** and the lower electrode **33** are preferably bonded to the upper surface and the lower surface of the dielectric body **20**, respectively, with an adhesive layer such as a double-sided tape, for example (not illustrated). The side electrode **32** is not bonded to the side surface of the dielectric body **20**, and a gap **25** is preferably provided between the side electrode **32** and the side surface.

An opening **34** and a slit **35** are preferably provided in the upper electrode **31**. The wireless IC element **50** is disposed at feeding portions **35***a* and **35***b* on opposite sides of the slit **35**. The wireless IC element **50** will be described in detail later with reference to FIGS. **15** to **18**. A coupling between the wireless IC element **50** and the feeding portions **35***a* and **35***b* is preferably achieved by electromagnetic field coupling or electrical direct coupling using solder bumps, for example.

In the wireless IC device **10**A, when a predetermined high-frequency signal is transmitted from the wireless IC element **50** to the feeding portions **35***a* and **35***b*, current is concentrated around the opening **34**. This current-concentrating portion functions as a loop magnetic field electrode having a predetermined length, and has a predetermined potential difference with respect to the feeding portions **35***a* and **35***b*. The predetermined potential difference of the loop magnetic field electrode is transmitted to the upper electrode **31**. As a result, the upper electrode **31** has a potential difference with respect to the lower electrode **33** and operates as a patch antenna. Thus, a signal characteristic (for example, a wide-band frequency characteristic) supplied from the feeding portions **35***a* and **35***b* can be externally transmitted via the metal pattern **30**. When the metal pattern **30** externally receives a high-frequency signal, a current is similarly induced around the opening **34** and power is supplied from the feeding portions **35***a* and **35***b* to the wireless IC element **50**. In this case, the loop magnetic field electrode performs impedance matching between the wireless IC element **50** and the metal pattern **30**.

Since an electromagnetic field radiated from the metal pattern **30** is relatively weak, only short-distance communication can be established. As illustrated in FIG. **2**B, when the wireless IC device **10**A is attached to a metal body **40** via an adhesive layer **41**, the metal pattern **30** (the lower electrode **33**) is capacitively coupled to the metal body **40** and the metal body **40** radiates a strong electromagnetic field from a surface thereof. In this case, the wireless IC device **10**A can communicate with a reader/writer that is spaced apart from the wireless IC device **10**A by a significant distance. A capacitor provided between the metal pattern **30** and the metal body **40** may be infinite. That is, the lower electrode **33** may preferably be directly electrically connected to the metal body **40**.

In the wireless IC device **10**A, a radiator is defined by the flexible metal pattern **30** and the flexible dielectric body **20** including the slits **21**. Accordingly, even if the wireless IC device **10**A is attached to the curved surface of the metal body **40** (for example, a gas cylinder), the dielectric body **20** and the metal pattern **30** follow the curved surface and the occurrence of stress concentration between the dielectric body **20** and the metal pattern **30** is prevented. As a result, changes in a communication characteristic caused by the detachment or distortion of the metal pattern **30** are prevented and communication reliability is not reduced.

The dielectric body **20** can be suitably bent due to the slits **21**. In addition, since the slits **21** are preferably provided not only on the upper surface and the lower surface but also on the side surfaces of the dielectric body **20**, the flexibility of the dielectric body **20** is further increased. Furthermore, since the slits **21** are preferably configured so as to include at least ridge portions of the dielectric body **20** in the lengthwise direction, the flexibility of the dielectric body **20** is further increased.

In the first preferred embodiment, the upper electrode **31** and the lower electrode **33** of the metal pattern **30** are preferably bonded to the upper surface and the lower surface of the dielectric body **20**, respectively, but the side electrode **32** of the metal pattern **30** is preferably spaced apart from the side surface of the dielectric body **20** via the gap **25**. Accordingly, when the wireless IC device **10**A is attached to the curved surface of the metal body **40** and then the dielectric body **20** is bent (see FIG. **2**B), the gap **25** becomes slightly smaller. That is, the gap **25** absorbs tensile stress applied to the side electrode **32** when the dielectric body **20** and the metal pattern **30** are bent. Alternatively, only one of the upper electrode **31** and the lower electrode **33** may be bonded to the dielectric body **20**.

The width of the metal pattern **30** is preferably less than that of the dielectric body **20**. That is, the metal pattern **30** is preferably provided or attached inside ridge portions **20***a* and **20***b* of the dielectric body **20** (see, FIG. **1**B). Therefore, it is difficult to detach the metal pattern **30** from side portions of the dielectric body **20**.

The slits **21** are also used to fix the curvature of the dielectric body **20**. That is, as illustrated in FIG. **3**A, when the dielectric body **20** is bent, the adhesive layer **41** preferably enters the slits **21** and portions **41***a* of the adhesive layer **41** are fixed to the slits **21**. Thus, the slits **21** contribute to fixing the curvature of the dielectric body **20**, that is, to maintaining the shape of the dielectric body **20**.

Preferably the slits **21** have a long strip shape as illustrated in FIG. **3**B. In this case, when the dielectric body **20** is bent (see, FIG. **3**C), the adhesive layer **41** that enters the openings of the slits **21** hardens and is more easily fixed to the dielectric body **20**. The slits **21** further contribute to fixing the curvature of the dielectric body **20**.

Second Preferred Embodiment

As illustrated in FIGS. **4**A to **4**C, in a wireless IC device **10**B according to the second preferred embodiment of the present invention, the opening **34** and the slit **35** of the metal pattern **30** are preferably arranged at the approximate center of the upper electrode **31**, the metal pattern **30** defining a radiator. The upper electrode **31**, a pair of the side electrodes **32**, and the lower electrode **33** are preferably arranged so as to substantially encircle the dielectric body **20**.

The depth of the slits **21** provided on the upper surface of the dielectric body **20** is preferably different from that of the slits **21** provided on the lower surface of the dielectric body **20**. That is, the depth of the slits **21** on the lower surface is preferably slightly greater than that of the slits **21** on the upper surface. When the wireless IC device **10**B is attached to the convex curved surface of the metal body **40** illustrated in FIGS. **2**A and **2**B, the dielectric body **20** can more easily bend since the depth of the slits **21** on the lower surface thereof is relatively large. Except for the above-described features, the configuration and operational effects according to the second preferred embodiment are substantially the same as those according to the first preferred embodiment.

Third Preferred Embodiment

A wireless IC device **10**C according to the third preferred embodiment of the present invention has a configuration similar to the configuration described in the second preferred embodiment as illustrated in FIG. **5**. In the wireless IC device **10**C, a slit **33***a* is preferably arranged at the approximate center of the lower electrode **33** so that it traverses the lower electrode **33**. The metal pattern **30** is preferably capacitively coupled with a capacitance element defined by the slit **33***a* and functions as a loop radiator. In the third preferred embodiment, the slits **21** are provided only on the lower surface of the dielectric body **20**. Except for the above-described features, the configuration and operational effects according to the third preferred embodiment are substantially the same as those according to the first preferred embodiment.

Modifications of the Dielectric Body

The shape and position of the dielectric body **20** may be as follows. For example, as illustrated in FIG. **6**, the slits **21** may preferably be arranged on the upper surface and the lower surface of the dielectric body **20** so that the positions of the slits **21** on the upper surface and the positions of the slits **21** on the lower surface do not overlap. As illustrated in FIG. **7**, the depth of the slits **21** may preferably be adjusted so that the slits **21** closer to the approximate center of the dielectric body **20** where the feeding portions are disposed have a smaller depth than those farther from the approximate center of the dielectric body **20**. As illustrated in FIG. **8**, the slit **21** may preferably extend not only in the Y direction but also in the X direction. The dielectric body **20** can easily bend along the curved surface of the metal body **40** in accordance with the shape and position of the slit **21**. As illustrated in FIG. **7**, the depth of the slits **21** may preferably be adjusted so that the slits **21** closer to the approximate center of the dielectric body **20** where the feeding portions are disposed have a smaller depth than those farther from the approximate center of the dielectric body **20**. Accordingly, stress concentration at the wireless IC element **50** is prevented.

As illustrated in FIG. **9**, the slit **21** may preferably have an oval shape in plan view. Concave portions such as the slits **21** provided in the dielectric body **20** may have various shapes and structures. For example, a dome-shaped concave portion and a dome-shaped convex portion may be alternately disposed at the dielectric body **20**, or the dielectric body **20** may have a corrugated surface.

Fourth Preferred Embodiment

In a wireless IC device **10**D according to the fourth preferred embodiment of the present invention, as illustrated in FIGS. **10**A to **10**C, the metal pattern **30** is preferably attached to the surface of a flexible resin film **28**, that may be a double-sided tape, for example, and the flexible resin film **28** is preferably wrapped around the dielectric body **20** from the upper surface to the lower surface of the dielectric body **20**. Similar to above-described preferred embodiments, in this case, it is preferable that the gap **25** be provided between the side surface of the dielectric body **20** and the flexible resin film **28**.

Except for the above-described features, the configuration and operational effects according to the fourth preferred embodiment are the same as those according to the first preferred embodiment.

In the fourth preferred embodiment, as illustrated in FIG. **10**B, the wireless IC element **50** may preferably be disposed on the metal pattern **30** before the metal pattern **30** is wrapped around the dielectric body **20**. This is advantageous for manufacturing a wireless IC device. In the fourth preferred embodiment, the opening **34** and the slit **35** may not be provided in the upper electrode **31** of the metal pattern **30**, and the upper electrode **31** may be divided into two portions so as to obtain feeding portions and the feeding portions may be connected to the wireless IC element **50**.

Fifth Preferred Embodiment

As illustrated in FIG. **11**, a wireless IC device **10**E according to the fifth preferred embodiment of the present invention has a configuration similar to that described in the fourth preferred embodiment. In the wireless IC device **10**E, the side electrode **32** facing the side surface of the dielectric body **20** is preferably arc-shaped and the area of the gap **25** is relatively large. Except for the above-described features, the configuration and operational effects according to the fifth preferred embodiment are substantially the same as those according to the first preferred embodiment.

Sixth Preferred Embodiment

As illustrated in FIG. **12**, in a wireless IC device **10**F according to the sixth preferred embodiment of the present invention, preferably, a cavity portion **22** is provided at the approximate center of the dielectric body **20**, the metal pattern **30** is attached to the lower surface of a flexible resin film **29**, and the wireless IC element **50** provided on the metal pattern **30** is disposed in the cavity portion **22**. The flexible resin film **29** and the lower electrode **33** are preferably divided by a slit **29***a* and the slit **33***a*, respectively. The flexible resin film **29** from one end of the slit **29***a* to the other end of the slit **29***a* and the metal pattern **30** from one end of the slit **33***a* to the other end of the slit **33***a* are preferably wound around the dielectric body **20** and are attached to the dielectric body **20**. The cavity portion **22** may be a through hole or a cavity, for example.

In the sixth preferred embodiment, the metal pattern **30** is capacitively coupled with a capacitance element defined by the slit **33***a*, and functions as a loop radiator. Except for the above-described features, the configuration and operational effects according to the sixth preferred embodiment are substantially the same as those according to the first preferred embodiment. In the sixth preferred embodiment, the wireless IC element **50** can be protected by disposing the wireless IC element **50** in the cavity portion **22**. It is preferable that the cavity portion **22** be closed by the lower electrode **33**.

Seventh Preferred Embodiment

FIG. **13** illustrates a first exemplary preferred attachment of a wireless IC device **10**G according to the seventh preferred embodiment of the present invention. The wireless IC device **10**G preferably includes a protection cover **45** arranged to cover the dielectric body **20**, the metal pattern **30**, and the wireless IC element **50**. The protection cover **45** is preferably attached to the metal body **40** with an adhesive **46** so that it covers the wireless IC device **10**G attached to the metal body **40**.

When the metal body **40** is a gas cylinder, it may be left outdoors or be handled roughly. In such a case, the protection cover **45** effectively protects the dielectric body **20** and the metal pattern **30** from a surrounding environment and shock.

Eighth Preferred Embodiment

FIG. **14** illustrates a second exemplary preferred attachment of a wireless IC device **10**H according to the eighth preferred embodiment of the present invention. In the wireless IC device **10**H, a double-sided tape **47** is preferably provided on the lower surface of the protection cover **45** described in the seventh preferred embodiment. The double-sided tape **47** is used to attach the wireless IC device **10**H to the metal body **40** and protect the dielectric body **20** and the metal pattern **30** along with the protection cover **45**. The double-sided tape **47** may preferably be a film, for example. In this case, the double-sided tape **47** is bonded to the lower surface of the protection cover **45** and the metal body **40** with an adhesive.

Wireless IC Element

The wireless IC element **50** will be described below. The wireless IC element **50** may include a wireless IC chip **51** arranged to process a high-frequency signal as illustrated in FIG. **15**, or may include the wireless IC chip **51** and a feeding circuit board **65** including a resonance circuit having a predetermined resonance frequency as illustrated in FIG. **16**.

The wireless IC chip **51** illustrated in FIG. **15** preferably includes a clock circuit, a logic circuit, and a memory circuit, and stores necessary information. On the lower surface of the wireless IC chip **51**, input/output terminal electrodes **52** and mounting terminal electrodes **53** are provided. The input/output terminal electrodes **52** are preferably electrically connected to the feeding portions **35***a* and **35***b* via metal bumps. The metal bumps are preferably made of, for example, Au or solder.

When the wireless IC element **50** includes the wireless IC chip **51** and the feeding circuit board **65** as illustrated in FIG. **16**, the feeding circuit board **65** may include various feeding circuits, including a resonance/matching circuit. For example, as illustrated in an equivalent circuit diagram in FIG. **17**, a feeding circuit **66** including inductance elements L1 and L2 that have different inductance values and opposite phases and are magnetically coupled to each other (represented by a mutual inductance M) may preferably be used. The feeding circuit **66** has a predetermined resonance frequency, and performs impedance matching between the wireless IC chip **51** and the metal pattern **30**. The wireless IC chip **51** and the feeding circuit **66** may be electrically connected or be connected via an electromagnetic field.

The feeding circuit **66** preferably transmits a high-frequency signal of a predetermined frequency received from the wireless IC chip **51** to the above-described antenna and supplies a received high-frequency signal to the wireless IC chip **51** via the antenna. Since the feeding circuit **66** has a predetermined resonance frequency, it can easily perform impedance matching and the electrical length of an impedance matching circuit, that is, the electrical length of the loop metal pattern **30**, can be reduced.

Next, the structure of the feeding circuit board **65** will be described. As illustrated in FIGS. **15** and **16**, the input/output terminal electrodes **52** of the wireless IC chip **51** are preferably connected to feeding terminal electrodes **142***a* and **142***b* provided on the feeding circuit board **65** via metal bumps, and the mounting terminal electrodes **53** of the wireless IC chip **51** are preferably connected to mounting terminal electrodes **143***a* and **143***b* formed on the feeding circuit board **65** via metal bumps.

As illustrated in FIG. **18**, the feeding circuit board **65** is preferably obtained by laminating, press-bonding, and firing ceramic sheets **141***a* to **141***h* each made of a dielectric or a magnetic substance, for example. Insulating layers included in the feeding circuit board **65** are not limited to ceramic sheets, and may be resin sheets made of a thermosetting resin such as liquid crystal polymer or a thermoplastic resin, for example. On the ceramic sheet **141***a* in the uppermost layer, the feeding terminal electrodes **142***a* and **142***b*, the mounting terminal electrodes **143***a* and **143***b*, and via-hole conductors **144***a*, **144***b*, **145***a*, and **145***b* are provided. The via-hole conductors **144***a* and **145***a* are connected to each other via the feeding terminal electrode **142***a*. The via-hole conductors **144***b* and **145***b* are connected to each other via the feeding terminal electrode **142***b*. On each of the ceramic sheets **141***b* to **141***h* in the second to eighth layers, a wiring electrode **146***a* defining the inductance element L**1** and a wiring electrode **146***b* forming the inductance element L**2** are provided and via-hole conductors **147***a*, **147***b*, **148***a*, and **148***b* are provided as necessary.

By laminating the ceramic sheets **141***a* to **141***h*, the inductance element L**1** is defined by the wiring electrodes **146***a* that are helically connected to each other by the via-hole conductor **147***a* and the inductance element L**2** is defined by the wiring electrodes **146***b* that are helically connected to each other by the via-hole conductor **147***b*. A capacitor is defined between the wiring electrodes **146***a* and **146***b*.

An end portion **146***a*-**1** of the wiring electrode **146***a* on the ceramic sheet **141***b* is connected to the feeding terminal electrode **142***a* via the via-hole conductor **145***a*. An end portion **146***a*-**2** of the wiring electrode **146***a* on the ceramic sheet **141***h* is connected to the feeding terminal electrode **142***b* via the via-hole conductors **148***a* and **145***b*. An end portion **146***b*-**1** of the wiring electrode **146***b* on the ceramic sheet **141***b* is connected to the feeding terminal electrode **142***b* via the via-hole conductor **144***b*. An end portion **146***b*-**2** of the wiring electrode **146***b* on the ceramic sheet **141***h* is connected to the feeding terminal electrode **142***a* via the via-hole conductors **148***b* and **144***a*.

In the feeding circuit **66**, since the inductance elements L**1** and L**2** are wound in opposite directions, magnetic fields generated at the inductance elements L**1** and L**2** cancel each other out. Since the magnetic fields are cancelled out, it is necessary to extend the wiring electrodes **146***a* and **146***b* so as to obtain desired inductances. When the lengths of the wiring electrodes **146***a* and **146***b* are increased, a Q value is reduced. As a result, the steepness of a resonance characteristic is eliminated and a wide band is obtained around a resonance frequency.

The inductance elements L**1** and L**2** are preferably provided at different positions on the left and right sides in a perspective plan view of the feeding circuit board **65**. The magnetic fields generated at the inductance elements L**1** and L**2** are preferably opposite in direction. As a result, when the feeding circuit **66** is coupled to an antenna, currents in opposite directions are excited at the antenna. Thus, a current can be generated at an adjacent metal plate, and the metal plate can operate as a radiating element (antenna) with a potential difference produced by the generated current.

By disposing a resonance/matching circuit in the feeding circuit board **65**, the resonance/matching circuit can prevent a characteristic change caused by an external product and prevent the deterioration in the quality of communication. By arranging the wireless IC chip **51** of the wireless IC element **50** at the approximate center of the feeding circuit board **65** in the thickness direction, the wireless IC chip **51** is prevented from being destroyed and the mechanical strength of the wireless IC element **50** is increased.

A wireless IC device according to preferred embodiments of the present invention is not limited to the above-described wireless IC devices. Various changes can be made to a wireless IC device according to preferred embodiments of the present invention without departing from the spirit and scope of the present invention.

In particular, a dielectric body may not be substantially rectangular parallelepiped and may be made of a thermosetting resin (rubber, an elastomer, or an epoxy resin) or a thermoplastic resin (a polyimide), for example. Alternatively, the dielectric body may be made of, for example, low-temperature co-fired ceramic (LTCC), for example, and include multiple layers as long as the dielectric body has sufficient flexibility with concave portions provided thereon.

As described above, preferred embodiments of the present invention are useful for a wireless IC device, and, in particular, are advantageous to prevent the detachment of a radiator from a body and changes in a communication characteristic even if a wireless IC device is attached to a curved surface.

While preferred embodiments of the present invention have been described above, it is to be understood that variations and modifications will be apparent to those skilled in the art without departing from the scope and spirit of the present invention. The scope of the present invention, therefore, is to be determined solely by the following claims.

What is claimed is:

1. A wireless IC device comprising:

a dielectric body including an upper surface and a lower surface;

a radiator provided on a surface of the dielectric body; and

a wireless IC element coupled to a feeding portion of the radiator; wherein

the radiator includes a flexible metal pattern;

a plurality of concave portions are provided on at least one of the upper and lower surfaces of the dielectric body so as to increase a flexibility of the dielectric body; and

each of the plurality of concave portions includes an opening at the respective upper or lower surface of the dielectric body;

the plurality of concave portions are open and not filled with conductive material; and

the radiator is disposed on the at least one of the upper and lower surfaces of the dielectric body on which the plurality of concave portions are provided, extends across the openings of the plurality of concave portions, and is not in contact with any surfaces of any of the plurality of concave portions.

2. The wireless IC device according to claim **1**, wherein the radiator is disposed inside ridge portions of the dielectric body.

3. The wireless IC device according to claim **2**, wherein the plurality of concave portions are arranged so as to include at least the ridge portions of the dielectric body.

4. The wireless IC device according to claim **1**, wherein

the radiator extends from the upper surface to the lower surface via a side surface of the dielectric body; and

the radiator is bonded to at least one of the upper surface or the lower surface and is not bonded to the side surface.

5. The wireless IC device according to claim **1**, wherein the radiator is provided on a flexible film.

6. The wireless IC device according to claim **1**, wherein the plurality of concave portions provided on at least one of the upper and lower surfaces of the dielectric body are slits.

7. The wireless IC device according to claim **6**, wherein the slits are provided on the upper surface and the lower surface of the dielectric body.

8. The wireless IC device according to claim **7**, wherein the slits are also provided on side surfaces of the dielectric body.

9. The wireless IC device according to claim **6**, wherein a depth of the slits provided on the upper surface of the dielectric body is different from a depth of the slits provided on the lower surface of the dielectric body.

10. The wireless IC device according to claim **6**, wherein positions of the slits provided on the upper surface of the dielectric body and positions of the slits provided on the lower surface of the dielectric body do not overlap one another.

11. The wireless IC device according to claim **6**, wherein the slits arranged closer to the feeding portion from end portions of the dielectric body have a smaller the depth than slits arranged farther from the feeding portion.

12. The wireless IC device according to claim 1, further comprising a protection member arranged to cover the dielectric body, the radiator, and the wireless IC element.

13. The wireless IC device according to claim 1, wherein the wireless IC element is a wireless IC chip arranged to process a predetermined radio signal.

14. The wireless IC device according to claim 1, wherein the wireless IC element includes a wireless IC chip arranged to process a predetermined radio signal and a feeding circuit board including a feeding circuit having a predetermined resonance frequency.

15. A wireless IC device comprising:

a dielectric body including an upper surface and a lower surface;

a radiator provided on one of the upper and lower surfaces of the dielectric body; and

a wireless IC element coupled to a feeding portion of the radiator; wherein

the radiator includes a flexible metal pattern;

a plurality of concave portions are provided on at least one of the upper and lower surfaces of the dielectric body so as to increase a flexibility of the dielectric body;

each of the plurality of concave portions includes an opening at the respective upper or lower surface of the dielectric body;

the dielectric body is attached to a surface of a metal body;

the plurality of concave portions are open and not filled with conductive material; and

the radiator is disposed on the at least one of the upper and lower surfaces of the dielectric body on which the plurality of concave portions are provided, extends across the openings of the plurality of concave portions, and is not in contact with any surfaces of any of the plurality of concave portions.

16. The wireless IC device according to claim 15, further comprising:

a protection member arranged to cover the dielectric body, the radiator, and the wireless IC element.

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